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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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SPAWNING BIOMASS OF PACIFIC SARDINE (*SARDINOPS SAGAX*) ESTIMATED FROM THE DAILY EGG PRODUCTION METHOD OFF CALIFORNIA IN 2013

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EXECUTIVE SUMMARY

The 2013 daily egg production method (DEPM) survey was conducted within standard DEPM area (i.e., in the California Cooperative Fisheries Investigation, CalCOFI, sampling grid lines 60.0-95.0), encompassing the spawning core area of Pacific sardine off California from north of San Francisco to San Diego. The spawning biomass of the Pacific sardine (*Sardinops sagax*) in April 2013 was estimated from the DEPM based on two methods: 1) the traditional method where the egg production (P_0) was a weighted mean while each adult parameter was an unstratified estimate; and 2) a stratified procedure where the estimate of total spawning biomass is the sum of the estimated spawning biomass in each of two regions representing high and low spawning activity. The two estimates of the spawning biomass were 144,880 mt (CV = 0.36) and 141,002 mt (CV = 0.34), respectively, within a total survey area of 141,397 km^2 (CalCOFI lines 63.3-91.7). The daily egg production estimate (P_0, an average weighted by area) was 1.34/.05m^2 (CV = 0.299). The estimates of female spawning biomass calculated by the two methods were 84,972 (CV = 0.33) and 82,182 mt (CV = 0.30), respectively.

Pacific sardine spawning biomass was estimated from 121 females collected from 15 positive trawls during the survey. Trawling was conducted randomly at CalCOFI stations, which resulted in sampling adult sardines in both the high and the low sardine egg-density regions of the surveyed area. During the 2013 survey, the number of tows positive for mature female sardines was 8 in the high egg-density region and 7 in the low egg-density region. In addition, three tows contained only male sardine. The daily specific fecundity of this group of females was computed to be 26.22 eggs/population weight (g)/day using the following estimates of reproductive parameters: *F*, mean batch fecundity, 41,339 eggs/batch (CV = 0.06); *S*, fraction spawning per day, 0.149 females spawning per day (CV = 0.16); W_f, mean female fish weight, 138.18 g (CV = 0.03); and *R*, sex ratio of females by weight, 0.586 (CV = 0.09).

The time series of spawning biomass presented in the table below was one of the fishery-independent indices of relative abundance in the annual stock assessment of the Pacific sardine from 1994 to 2014. Since 2009, the time series of total spawning biomass was replaced by female spawning biomass for years when sufficient trawl samples were available. In other years

Calendar year	Fishing season	Total egg production	Female spawning biomass (CV)	Total spawning biomass[a] (CV)
1994	1993	73374	69065 (0.30)	128531 (0.31)
2004	2003	307795	145274 (0.23)	234958 (0.28)
2005	2004	486950	459943 (0.60)	755657 (0.52)
2007	2006	306297	198404 (0.31	380601 (0.39)
2008	2007	128118	66395 (0.28)	126148 (0.40)
2009	2008	162188	99162 (0.24)	185084 (0.28)
2010	2009	97838	58447 (0.42)	108280 (0.46)
2011	2010	364798	219386 (0.28	383286 (0.32)
2012	2011	227632	113178 (0.27)	282110 (0.43)
2013	2014	198472	82182 (0.30)	144880 (0.36)

[a] based on data in Table 6

when not enough mature females were captured (i.e.1996-2003 and 2006), the total egg production was used as inputs to the stock assessment of Pacific sardine. In 2013, sufficient mature females (121) were collected in the spring survey, and thus female spawning biomass was computed and was directly used in the 2014 stock assessment. The time series of spawning biomass showed that it fluctuated considerably during the 1994-2013 period. Spawning biomass peaked in 2005, declined from 2007 to 2010, but increased in 2011 before declining again in 2012 and 2013.

INTRODUCTION

Fishery independent surveys are critical for assessing and managing Pacific sardine stocks along the North American Pacific coast. These surveys can provide relative abundance indices to calibrate stock assessment and to monitor stock productivity as environmental conditions change. The Daily Egg Production method (DEPM) is one of two fishery-independent surveys that are currently used to assess the northern Pacific sardine stock from Ensenada to British Columbia and to set harvest guidelines for annual management in the USA. The DEPM was developed by Lasker (1985) to estimate the spawning stock biomass of northern anchovy (*Engraulis mordax*) based on growth, mortality and abundance of eggs and larvae, and the reproductive biology of this species. The method was later applied to assess the spawning of Pacific sardine off Califonia from 1986 to 1996 (Wolf 1988a, Wolf 1988b, Lo et al. 1996, Scannel et al. 1996, Barnes et al. 1997). Since 2004, spawning biomass computed from the DEPM has been integrated in annual stock assessments of Pacific sardine by: 1) calculating the daily egg production from ichthyoplankton survey data; 2) computing the reproductive parameters of females from adult fish samples; and 3) calculating the biomass of spawning adults.

Historically, various methods have been used to survey the spawning ground of Pacific sardine off California for the DEPM estimation. Prior to 1996 sardine egg production was estimated from CalCOFI Vertical Egg Tow (CalVET a.k.a Pairovet) plankton net samples; whereas adult fish were sampled to obtain specimens for batch fecundity, spawning fraction, sex ratio, and average female fish weight (Wolf 1988a, 1988b; Scannell et al. 1996; Macewicz et al. 1996; Lo et al. 1996). Since 1996, in addition to CalVET and Bongo nets, a Continuous Underway Fish Egg Sampler (CUFES) has been used to collect sardine eggs (Checkley, et al. 1997) in the upper 3m of surface water. During the 1997 sardine egg survey, CUFES was used to allocate CalVET tows in an adaptive sampling design (Hill et al. 1998, Lo et al. 2001). From 1998 to 2000, data on sardine eggs collected with both CalVET and CUFES during each April California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruise were used to estimate daily egg production (Hill et al. 1999). Starting in 2001, a cost-effective alternative has been adopted to calculate the DEPM index that reduces effort in calculation and egg staging of the CUFES collections. Egg production estimated from this revised index only uses CalVET egg samples, and yolk-sac larvae samples from both CalVET and Bongo net samples collected in the high-egg density area.

During the past decade, full-scale surveys have been conducted for collection of Pacific sardine eggs, larvae, and adults to better estimate the spawning biomass in the area off California between San Diego and San Francisco (Lo and Macewicz 2004; Lo et al. 2005; Lo and Macewicz 2006; Hill et al. 2006a, b; Lo et al. 2007a, b, 2008, Lo et al. 2009, 2010b, 2011, Lo et al. 2013). In 2004 the adult samples were taken primarily in the high-egg density area, but beginning in 2005 adult Pacific sardine samples for reproductive output were taken in both high and low sardine egg density areas. The ichthyoplankton samples taken during regular April CalCOFI cruises were also included in the spawning biomass computation. During 2006, 2008, and 2010-2012, the survey area was extended north to the US-Canadian border. The spawning biomass was computed for both the whole survey area (Cape Flattery, WA to San Diego, CA) and the standard DEPM survey area (from San Diego to San Francisco, CalCOFI line 95 to 60) in 2006, 2008 and 2010. However, in 2011 and 2012 biomass was only computed for the standard area because few eggs and adults were observed in the area north of CalCOFI line 60.0. Further, in some years the most southern

CalCOFI line occupied was not line 95. For examples, in 2012 and 2013 the most southern line was 93.8 and 91.7 respectively.

Since 2009, in addition to the estimates of spawning biomass based on the past procedure (i.e., where egg production was weighted by the size of each region and the adult parameters were estimated from all trawl samples in the entire survey area), an alternative estimator based on stratified sampling for each parameter was also included (Hill et al. 2009, 2010) for years when adequate adult samples were available (1986, 1987, 1994, 2004, 2005, 2007-present). Here, we report the time series of spawning biomass, female spawning biomass, and total egg production based on both the traditional method and the stratified estimation procedure.

MATERIALS AND METHODS

Data

The spring 2013 CPS-Sardine DEPM survey was conducted aboard the NOAA ship, *Bell M. Shimada* (April 6-April 30) and a chartered research vessel, the R/V *Ocean Starr* (April 8-May 3, Figures 1 and 2). The *Ocean Starr* covered the area off the west coast of the US from Oceanside, California to just south of Monterey Bay, California (CalCOFI lines 91.7 to 68.3) while the *Shimada* covered the area from Avila Beach, California to Half Moon Bay, California (CalCOFI lines 76.7 to 63.3). Because the Shimada conducted both a standard CalCOFI survey (April 8-April 22) and a sardine DEPM (April 23-April 30), only data collected during the DEPM portion were used for the spawning biomass estimate. Egg densities were low and no trawls were taken from the Shimada during the CalCOFI survey. To be consistent with previous year's estimates (i.e., 2009, 2010 and 2012) eggs and larval data from this survey were not used in the computation of egg production for 2013. During the DEPM survey, CalVET tows, Bongo tows, CUFES and surface trawls were conducted aboard both vessels. Data from DEPM surveys on both ships were included in the estimation of spawning biomass of Pacific sardines.

All ichthyoplankton tows follow specific protocols developed within the CalCOFI program and are conducted as follows. CalVET tows are fished vertically from 70 meters depth to the surface at a retrieval rate of 70 meters/minute. The mesh size of the net body and the codend are 150 μm and the frame opening diameter is 25 cm. Bongo tows consist of paired 71 cm rings connected by a central swivel. With depth permitting, the Bongo nets fish to a depth of 210 m through an oblique trajectory. The paired nets have a mesh size of 505 μm and the codends have a 333 μm mesh. The amount of water strained during the net tows is calculated using a GO digital flowmeter to measure distance traveled multiplied by the opening area of the frame. For a more detailed description please refer to Smith and Richardson (1977) and McClatchie (2013).

Sardine eggs and yolk-sac larvae collected with the CalVET net, and yolk-sac larvae collected with the Bongo net were used to model the sardine embryonic mortality curve. First, CUFES data from the ichthyoplankton surveys was used to map the spatial distribution of the sardine spawning population and to post-stratify the survey area into high-egg density (Region 1) and low-egg density (Region 2) areas (see Lo et al. 2001). Second, staged eggs from CalVET tows and yolk-sac larvae from CalVET and Bongo tows in the high-density area were used to model embryonic mortality in the high density area and the whole survey area. Third, the daily egg production (P_0) for these two areas were derived from the mortality curve equation.

During the 2013 CPS-Sardine DEPM survey, fifteen distinct transects were occupied by the vessels, excluding six CalCOFI lines. The *Shimada* occupied five lines and the *Ocean Starr* occupied ten lines. For the CPS-sardine DEPM survey, CalVET tows were taken at 4-nm intervals on each line after the egg density from each of two consecutive CUFES samples exceeded 1 egg/min, and CalVET tows were stopped after the egg density from each of two consecutive CUFES samples was less than 1egg/min.

In 2013, the survey was restricted within the DEPM standard area south of San Francisco to San Diego (CalCOFI line 60.0 - 95.00). The survey was conducted over an area size of 141,397 km^2 that was smaller than the area in 2012 (270,991 km^2) and that was the smallest area recorded since 1994 (380,175 km^2). This survey area was used to estimate the initial P_0, and post-stratified into two regions: the high sardine egg density and the low egg density. The high egg-density region was largely between CalCOFI lines 66.7 and 78.3 and CalCOFI lines 88.5 and 91.7 (Figure 1) where the egg density in CUFES collections was at least 1 egg per minute. The sizes of the high egg-density region and the standard DEPM survey area were calculated using the R function "*identify*" to select points for delineating a trapezoid area, and another R function "*areaPolygon*" in the geosphere-package (http://cran.r-project.org/web/packages/ geosphere/ geosphere.pdf) to estimate the area. The high egg-density region was 29,756.5 km^2 (21% of the standard DEPM area) and the low egg-density region was 111,640 km^2.

A total of 391 CUFES samples were collected in the *Ocean Starr* (283) and *Shimada* (113 collected after April 23) cruises over the whole survey area (Table 1). For the *Ocean Starr*, CUFES sampling intervals ranged from 7 to 74 minutes with a mean of 38.9 minutes and median of 30 minutes, and for *Shimada*, CUFES sampling intervals ranged from 11 to 94 minutes with a mean of 45.5 minutes and a median of 46 minutes depending on egg densities observed onboard. The total number of CalVET tows was 106 for the entire survey area, with all 106 in the standard DEPM survey area. A total of 49 CalVET samples caught at least one egg (Table 1), with the majority of the positive tows taken in Region 1. Egg densities from each CalVET sample and from the CUFES samples taken within an hour before and after the CalVET tow were paired and used to derive a conversion factor (E) from eggs/min of CUFES sample to CalVET catch (eggs/tow). We used a regression estimator to compute the ratio of mean eggs/min from CUFES to mean eggs/tow from CalVET: $E = \mu_y/\mu_x$, where y is eggs/min and x is eggs/tow.

For adult samples, the survey plan was to use the *Shimada* and the *Ocean Starr* to conduct 3-5 trawls a night either near regular CalCOFI stations or at random sites on the survey line regardless of the presence of sardine eggs in CUFES collections. At night a Nordic 264 rope trawl with 3.0 m^2 foam core doors was towed for 30 minutes at the surface (0-11 meters). The trawl was modified for surface trawling with Polyform floats attached to the head rope and trawl wings. The trawl was modified with a marine mammal excluder device placed midsection just forward of the codend. For the whole CPS-Sardine DEPM survey, trawling occurred from April 8 to May 3, 2013 and 18 of the 70 trawls conducted at night were positive for Pacific sardines. The 18 positive trawls with sardines were located throughout the survey area (Figure 1, Table 1 and 2).

Up to 50 sardines were randomly sampled from each positive trawl with more than 75 fish, or all were sampled if fewer than 76 fish were captured (Table 2). After the random subsample, additional mature females were randomly processed, if necessary, from the trawl catch to obtain 25 mature females per trawl for reproductive parameters or to obtain females for use in estimating batch fecundity. More than 76 fish were captured in only one of the trawls. Each fish was sexed, standard length (mm) and weight (g) were measured, otoliths were removed for aging, tissue was preserved in 95% ethanol for genetics, and, for females, ovaries were removed and preserved in 10% neutral buffered formalin. Each preserved ovary was blotted and weighed to the nearest milligram in the laboratory. Ovary wet weight was calculated as preserved ovary weight times 0.78 (unpublished data, CDFG 1986). A piece of each ovary was removed and prepared as hematoxylin and eosin (H&E) histological slides. All slides were analyzed for oocyte development, atresia, and postovulatory follicle age to assign female maturity and reproductive state (Macewicz et al. 1996). Finally, sardines were aged following methods described in Yaremko (1996) and Dorval et al. (2013).

Daily egg production (P_0)

All eggs and adults were collected south of San Francisco beginning at CalCOFI line 63.3 in the standard DEPM survey area. Therefore, the estimate of P_0, and thus spawning biomass for the standard DEPM survey area (i.e., the area between CalCOFI line 60.0 and 95) were also used for the entire survey area which differed from some of the previous years, e.g. 2006, that had separate area estimates. Appropriate parameter estimates required y the DEPM were obtained for each region.

Similar to the 2001-2005 procedure (Lo 2001), we used a net tow as the sampling unit. Sardine eggs from CalVET tows and sardine yolk-sac larvae from both CalVET and Bongo tows in Region 1 were used to compute egg production, primarily based on data from 10 transects (Figure 1 and 2). In high egg-density region, a total of 32 out of 40 CalVET samples contained at least 1 sardine egg (Table 1); these eggs were examined for their developmental stages following similar methods as in Moser and Ahlstrom (1985). In Region 2, 17 out of 66 CalVET tows caught sardine eggs.

Based on laboratory counts of sardine eggs in CUFES samples, 155 of the 391 collections were positive for sardine eggs over the DEPM area (south of CalCOFI line 60.0). In Region 1, there were 82 positive CUFES collections out of 95 total collections. In the DEPM Region 2, 73 of the total 296 collections were positive. (Figure 1 and Table 1).

To model the embryonic mortality curve, we included yolk-sac larvae (preserved larvae ≤ 5 mm notochord length), assuming that the mortality rate of yolk-sac larvae was the same as that of eggs (Lo 1986). Yolk-sac larval production was computed as the number of yolk-sac larvae/0.05m^2 divided by the duration of the yolk-sac stage (number of larvae/0.05m^2/day). Duration was computed based on the temperature-dependent growth curve (Table 3 of Zweifel and Lasker 1976) for each tow. For yolk-sac larvae caught by the Bongo net, larval abundance was further adjusted for size-specific extrusion from 0.505 mm mesh (Table 7 of Lo 1983) and for the percent of each sample that was sorted. The adjusted yolk-sac larvae/0.05m^2 was then computed for each tow and termed daily larval production/0.05m^2.

In the DEPM survey area, 49 of 106 CalVET and 9 of 63 Bongo samples had at least one yolk-sac larva (Table 1). In Region 1 (Figure 2), 11 of 40 CalVET and 9 out of 12 Bongo samples were positive for yolk-sac larvae, and in Region 2, 8 of 66 CalVET tows were positive, but no Bongo samples out of 51 were positive for yolk-sac larvae (Table 1).

Daily egg production in the high egg-density region ($P_{0,1}$)

Sardine eggs and yolk-sac larvae and their ages were used to construct an embryonic mortality curve (Lo et al. 1996). Pelagic egg samples typically comprised various groups of eggs representing different stages from several days of spawning, and the number of days (i.e. age) to reach these developmental stages is temperature dependent (Lasker 1985, Lo et al. 1996). A temperature-dependent stage-to-age model (Lo et al. 1996) was used to assign age to each stage, and to compute sardine egg density for each stage based on CalVET samples (Figure 3). Sardine eggs and estimated ages were used directly in nonlinear regression. Eggs ≤ 3h old and eggs older than 2.5 days were excluded because of possible bias. The average sea surface temperature for all CalVET tows from *Ocean Starr* was 13.94°C, while from the *Shimada* it was 13.23°C for the tows in the standard DEPM survey area.

The sardine embryonic mortality curve was modeled by an exponential decay curve (Lo et al. 1996):

$$P_t = P_{\mathbf{0}} e^{-zt} \qquad [1]$$

where P_t is either eggs/0.05m^2/day from CalVET tows or yolk-sac-larvae/0.05m^2/day from CalVET and Bongo tows, t is the age (days) of eggs or yolk-sac larvae from each tow and z is the daily instantaneous mortality rate. A weighted nonlinear regression was used to estimate two parameters in equation (1) where the weights were 1/SD. The standard deviation (SD) of eggs was 6.33, 4.84, 1.21, for day-one, day-two and day-three age groups from CalVET samples, respectively, and the SD for yolk-sac larvae was 1.17 and 1.43 from CalVET and Bongo samples, respectively.

A simulation study (Lo 2001) indicated that $P_{0,1}$ computed from a weighted nonlinear regression based on the original data points has a relative bias (RB) of -0.04 from the estimate, where the RB = (mean of 1,000 estimates - true value)/mean of 1,000 estimates. Therefore the bias-corrected estimate of egg production in Region 1 is calculated as $P_{0,1,c} = P_{0,1} * (1\text{- RB}) = P_{0,1} *(1.04)$, and $SE(P_{0,1,c}) = SE(P_{0,1}) * 1.04$.

Daily egg production in the low egg-density region ($P_{0,2}$)

Although 66 CalVET samples were taken in Region 2, only 17 tows had one or more sardine egg (Table 1). Eggs caught per tow ranged from 1 to 70 eggs with 95% of the catches containing fewer than 15 eggs (Figure 4). Therefore, we estimated daily egg production in Region 2 ($P_{0,2}$) as the product of the bias-corrected egg production in Region 1 ($P_{0,1,c}$) and the ratio (q) of egg density in Region 2 to Region 1 from CUFES samples, assuming the catch ratio of eggs/min from CUFES to eggs/tow from CalVET was the same for the whole survey area:

$$P_{0,2} = P_{0,1,c} q \qquad [2]$$

$$q = \frac{\sum_i \frac{\bar{x}_{2,i}}{\bar{x}_{1,i}} m_i}{\sum_i m_i} \qquad [3]$$

$$\mathrm{var}(q) = \frac{[n/(n-1)]\sum_i m_i^2 (q_i - q)^2}{\left(\sum_i m_i\right)^2}$$

where q is the ratio of eggs/min between the low density and high density areas, m_i was the total CUFES time (minutes) in the i[th] transect, $\bar{x}_{j,i}$ is eggs/min of the i[th] transect in the j[th] Region, and $q_i = \frac{\bar{x}_{2,i}}{\bar{x}_{1,i}}$ is the catch ratio in the i[th] transect. The estimates of q were computed from a total of 10 transect lines occupied by the *Ocean Starr* and/or the *Shimada* in Region 1.

Daily egg production (P_0)

P_0 was computed as the weighted average of $P_{0,1}$ and $P_{0,2}$:

$$\begin{aligned} P_0 &= \frac{P_{0,1,c} A_1 + P_{0,2} A_2}{A_1 + A_2} \qquad [4] \\ &= P_{0,1,c} w_1 + P_{0,2} w_2 \\ &= P_{0,1,c} [w_1 + q w_2] \end{aligned}$$

and

$$mse(P_0) = mse(P_{0,1,c})(w_1 + w_2 q)^2 + P_{0,1,c}^2 w_2^2 V(q) - mse(P_{0,1,c}) w_2^2 V(q)$$

(Goodman 1960) where mse ($P_{0,1,c}$) = v($P_{0,1}$) + bias^2 = v($P_{0,1}$) + ($P_{0,1}$ RB)^2
and $w_i = \frac{A_i}{A_1 + A_2}$, and A_i is the area size for i = 1 or 2 for the DEPM survey area.
The above P_0 was computed for the DEPM area between CalCOFI line 63.3 and 91.7. The size of the survey area is 141,397 km^2. The total egg production (TEP) is the numerator of equation 4 [P_0 * (A_1+A_2)].

Adult parameters

Four adult parameters are needed for estimation of spawning biomass: 1) daily spawning fraction or the number of spawning females per mature female per day (S); 2) the average batch fecundity (F); 3) the proportion of mature female fish by weight (sex ratio, R); and 4) the average weight of mature females (g, W_f). Population values for S, R, F and W_f were estimated using the methods of Picquelle and Stauffer (1985). Daily specific fecundity (number of eggs per population weight (g) per day) is $(RSF)/W_f$. The parameters were estimated for the DEPM area and separately for sardine females caught in each egg-density region. Correlations among all pairs of adult parameters were calculated for computing the variance of the estimate of spawning biomass (Parker 1985). In the past, the predicted batch fecundity for each female fish was calculated as $y = a + bx$ where x is the female weight (without ovary) and y is the predicted value. Therefore, to account for the deviation of batch fecundity from the regression line, we added an error term to the predicted value as $y = a + bx + e$ where error term e was a random number generated from a normal distribution with mean zero and a variance of the error terms from the regression analysis. An MS[1] Visual Basic program (Chen et al. 2003) was modified to more accurately describe batch fecundity variance and was used to summarize the trawl adult parameters, calculate adult parameter correlations and covariance, and estimate spawning biomass and its coefficient of variation.

Spawning fraction (S): In total, 121 mature female sardines were analyzed and considered to be a random sample of the population in the DEPM area. Histological criteria can be used to identify four different spawning nights: postovulatory follicles aged 44 – 54 hours old indicated spawning two nights before capture (A), postovulatory follicles aged about 20 – 30 hours old indicated spawning the night before capture (B), hydrated oocytes or new (without deterioration) postovulatory follicles indicated spawning the night of capture (C), and early stages of migratory-nucleus oocytes indicated that spawning would have occurred the night after capture (D). The daily spawning fraction can be estimated using the number of females spawning on one night, an average of several nights, or all nights. We used the average of the number of females identified as having spawned the night before capture (B) and those having spawned two nights before capture (A) since 2009 plus the adjusted number of mature females caught in each trawl (Table 2) to estimate the 2013 population spawning fraction (S_{12}) and variance (Picquelle and Stauffer 1985, Hill et al. 2009).

Batch fecundity (F): Batch fecundity (number of oocytes per spawn) was considered to be the number of migratory-nucleus-stage oocytes or the number of hydrated oocytes in the ovary (Hunter et al., 1985). We used the gravimetric method (Macewicz et al. 1996; Hunter et al. 1985, 1992) to estimate mean batch fecundity for 40 females caught during the April 2012 survey. The relationship of batch fecundity (F_b) to female weight (without ovary, W_{of}), as determined by simple linear regression, was $F_b = -9759 + 404.24W_{of}$,where $r^2 = 0.445$, variance of the slope was 6165.4, and W_{of} ranged from 69 to 168 g (Figure 5); the intercept did not differ from zero ($p = 0.347$). We used the equation $F_b = -9759 + 404.24W_{of} + e$ where the error term, e, was generated from a normal distribution with mean zero and variance of 67,258,833 to estimate batch fecundity for each of the 121 mature Pacific sardine females that were analyzed to estimate spawning frequency.

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Female weight (W_f): The observed female weight was adjusted downward for females with hydrated ovaries, because their ovary weights were temporarily inflated. We obtained the adjusted female weight by the linear equation W_f = -2.38 + 1.08W_{of} where W_f is wet weight and W_{of} is ovary-free wet weight based on data from non-hydrated mature females taken during the April 2013 Sardine DEPM survey.

Sex ratio (R): The female proportion by weight was determined for each trawl (or each collection). The average weight of males and females (calculated from the first 10 males and 25 females) was multiplied by the number of males or females in the collection of randomly selected fish to calculate total weight by sex in each collection. Thus, the female proportion by weight in each collection (Table 2) was calculated as estimated total female weight divided by estimated total weight in the sample. The estimate of the population's sex ratio by weight was also calculated (Picquelle and Stauffer, 1985).

Spawning biomass (B_s)

The spawning biomass was computed as:

$$B_s = \frac{P_0 AC}{RSF/W_f} \qquad [5]$$

where A is the survey area in units of 0.05m^2, S is the fraction of mature females spawning per female per day, F is the batch fecundity (number of eggs per mature female released per spawning event), R is the fraction of mature female fish by weight (sex ratio), W_f is the average weight of mature females (g), and C is the conversion factor from grams (g) to metric tons (mt). P_0A is the total daily egg production in the survey area, and the denominator (RSF/W_f) is the daily specific fecundity (number of eggs/population weight (g)/day).

The variance of the spawning biomass estimate $\left(\hat{B}_s\right)$ was computed using Taylor expansion and in terms of the coefficient of variation (CV) for each parameter estimate and covariance for adult parameter estimates (Parker 1985):

$$VAR\left(\hat{B}_s\right) = \hat{B}_s^{\,2}\left[CV\left(\hat{P}_0\right)^2 + CV\left(\hat{W}_f\right)^2 + CV\left(\hat{S}\right)^2 + CV\left(\hat{R}\right)^2 + CV\left(\hat{F}\right)^2 + 2COVS\right] \qquad [6]$$

The last term, involving the covariance term, on the right-hand side is

$$COVS = \sum_i \sum_{i<j} sign \frac{COV\left(x_i, x_j\right)}{x_i x_j}$$

where x's are the adult parameter estimates, and subscripts i and j represent different adult parameters, e.g., $x_i = F$ and $x_j = W_f$. The sign of any two terms is positive if they are both in the numerator of B_S or denominator of B_S (equation 5); otherwise, the sign is negative. The covariance term is

$$COV(x_{i,}x_j) = \frac{[n/(n-1)]\sum_k m_k(x_{i,k} - x_i)g_k(x_{j,k} - x_j)}{\left(\sum_k m_k\right)\left(\sum_k g_k\right)}$$

where k refers to k^{th} tow, and k = 1,…,n. The terms of m_k and g_k are sample sizes and $x_{i,k}$ and $x_{j,k}$ are sample means from the k^{th} tow for x_i and x_j respectively.

The survey area was post-stratified into two regions based on the presence of sardine eggs: Region 1 (high-density area) and Region 2 (low-density area). Thus, equation (5) can be applied to the whole survey area and/or to each of the two regions depending on the availability of data. For the female spawning biomass (fs.biomass), one of the inputs to the stock assessment, the sex ratio (R), was excluded from equations (5) and (6). The estimate of female spawning biomass was the sum of the estimate from each of the two regions, which is referred to as the stratified procedure. The traditional method is to obtain a weighted mean for P_0 (equation 4), while each of the adult parameter was an un-stratified estimate.

RESULTS

Egg density from CalVET

The stages of eggs collected from CalVET ranged from I to XII (Figure 3). Stage I are newly spawned eggs with no cell divisions; whereas stage XII included newly hatched sardines. In 2013 the distribution of egg density by egg developmental stage peaked at stage 3, which began with the formation of the segmentation cavity (i.e., the space formed between the blastodisc and the yolk mass during late cleavage). The distribution of egg density-at-stage in the whole area and the high egg density region was closely similar. Finally, the average sea surface temperature computed for CalVET tows with ≥1 egg in the DEPM survey area was 13.51°C.

Daily egg production (P_0) for the standard DEPM survey area

In Region 1, the initial daily egg production ($P_{0,1}$) from the mortality curve was 5.26/0.05 m^2/day (CV = 0.29; equation 1 and Figure 6). The bias-corrected egg production, ($P_{0,1,c}$) was 5.47 (CV = 0.29) (Table 3) for an area of 29,176 km^2 (south of CalCOFI line 60.0). The ratio (q) of egg density between Region 2 and Region 1 from CUFES samples was 0.049 (CV = 0.35) (equation 3). The egg production ($P_{0,2}$) in Region 2 of the standard survey area was 0.27 (CV = 0.44) for an area of 112,221 km^2, compared to 0.24/0.05m^2/day (CV = 0.27) in 2012 for an area of 238,669 km^2. Egg mortality (0.64 (CV = 0.16)) was similar to the 2012'estimate, but higher than estimates from the 1994-2011period (Table 3 and 4). The P_0 for the standard DEPM survey area was 1.34/0.05m^2 (0.299) (equation 4) for 141,397 km^2.

Catch ratio between CUFES and CalVET (E)

Although this ratio is no longer needed in the current estimation procedure, we computed it for comparison purposes. The catch ratio of eggs/min to eggs/tow (eggs/min = E * eggs/0.05 m^2) was computed from 49 pairs of CalVET tows and CUFES collections from the *Ocean Starr* and *Shimada* cruises (Figure 4). The eggs/min corresponding to each positive CalVET tow was the mean of all CUFES collections taken from one hour before to one hour after each positive CalVET tow. The catch ratio, 0.1216 (CV = 0.17), was higher than those in 2012 (0.0338, CV=0.34), 2011 (0.0589, CV = 0.21) and 2010 (0.077, CV = 0.14). A ratio of 0.1216 means that one egg/tow from a CalVET tow was equivalent to approximately 0.1216 egg/min from a CUFES sample, or one egg/minute from the CUFES was equivalent to 8.22 eggs/tow from the CalVET sample.

The ratio of egg densities of two regions from pump samples (q)

The q value (ratio of eggs/min in Region 2 to eggs/min in Region 1) serves as the calibration factor to estimate $P_{0,2}$ in Region 2 (equation 2). It is needed because low abundance of eggs observed in Region 2 prevents us from using the egg mortality curve to directly estimate $P_{0,2}$. For the 2013 survey, q was obtained from transects in Region 1 that had at least five CUFES collections taken. A total of 10 transect lines, all south of CalCOFI line 66.7, were used to compute q. The estimate was 0.049 (CV = 0.34).

Adult parameters

In the April 2013 DEPM survey area off California (from CalCOFI lines 63.3 to 91.7, about (37.18° – 32.36°N), Pacific sardines were found in 18 tows (Table 2, Figure 1). Mature female sardine were caught in 15 tows, and 3 tows contained only male sardine (Table 2). Standard length (SL) of the randomly obtained sardines in each trawl ranged from 185 to 248 mm for 101 males and from 180 to 259 mm for 124 females. The smallest mature female was 180 mm SL. Since no immature female sardines were captured during the 2013 survey, the length at which 50% of females are mature (ML_{50}) was not calculated.

The DEPM survey area off California in 2013 was 141,397 km^2. Estimates of reproductive parameters of sardines for the individual trawls (up to 25 mature females analyzed per trawl) are given in Table 2. The mature female sardine reproductive parameters in the standard DEPM survey area, estimated from 15 positive trawls (Table 2) and 121 mature females, were F, mean batch fecundity, 41,339 eggs/batch (CV = 0.06); S, fraction spawning per day, 0.149 females spawning per day (CV = 0.16); W_f, mean female fish weight, 138.18 g (CV = 0.03); and R, sex ratio of females by weight, 0.586 (CV = 0.09) (Table 5). The average interval between spawning bouts (spawning frequency) was about 7 days (inverse of spawning fraction or 1/0.149), and the daily specific fecundity was 26.22 eggs/population weight (g)/day (Table 5). The correlation matrix for the adult parameter estimates for the DEPM Region 1 and Region 2 and the whole DEPM area is shown in Table 5. We also provide estimates of each adult parameter in each region (Table 5), primarily because they are used to compute female spawning biomass, which is the input of fishery-independent spawning biomass time series to the stock assessment (Hill et al. 2011).

Spawning biomass (B_s)

The final estimate of spawning biomass of Pacific sardines in 2013 using the traditional method (equation 1 and 4, Tables 3, 4, and 6) was 144,880 mt (CV = 0.36) for the standard DEPM survey area of 141,397 km^2 off California. The yearly point estimates of spawning biomass of Pacific sardine off California in the 1994 – 2013 period were: 127,102; 79,997; 83,176; 409,579; 313,986; 282,248; 1,063,837; 790,925; 206,333; 485,121; 281,639; 621,657; 837,501; 392,492; 117,426; 185,084; 108,280; 383,286; 282,110; and 144,880mt, respectively (Table 4). Based on the stratified procedure, the estimate of the 2013 spawning biomass was 141,002 mt (CV = 0.34) (Table 3).

The estimate of the female spawning biomass for the DEPM survey area was 82,182 mt (CV = 0.30) and 84,972 mt (CV = 0.33) based on the stratified procedure and the traditional method respectively (Table 6). The former with estimates of previous years was used as one relative abundance index time series input to the Pacific sardine stock assessment (Table 6). Note the spawning biomass estimates prior to 2009 could be different between Tables 4 and 6 due to the different estimation procedure for the spawning fraction. Beginning in 2009, the spawning fraction was the average of spawning fraction 1 and 2 nights before the capture (S_{12}) (Table 6) while before 2009, the spawning fraction was based only on female spawning 1 night before capture (S_1) (Table 4).

DISCUSSION

Sardine eggs

In April 2013 high densities of eggs were concentrated within two main expanses, between CalCOFI lines 66.7 and 78.3 and between CalCOFI lines 85.0 and 91.7, covering an area of 29,176 km^2. This area defined as Region 1 was similar to 2012 (Figure 1, Lo et al. 2013), but was much smaller than the high density area in 2011 (Lo et al. 2011). The survey was restricted within the DEPM standard area in 2013, thus it is not known whether spawning occurred north of this area as in 2006 and 2008. However, it is worth noting that no sardine eggs were caught north of CalCOFI line 60.0 in both 2011 and 2012 (Lo et al. 2012, Lo et al. 2013). The distribution of egg density by egg development stage in 2013 peaked at stage 3, and thus was different from 2012 which exhibited two peaks (stages 3 and 5) and from those in previous years when stage 6 or stages 6-9 had the highest density (Lo et al. 2009 and 2010b). The average sea surface temperature for positive CalVET tows in this DEPM survey area was 13.51°C, which was similar to 2011 and 2012, but lower than 2010 estimate (Lo et al. 2010b).

The daily egg production rate of 5.47/0.05m^2 in the high-density area was similar as the 2012 and 2013's+ estimates, but was much higher than estimates from 2007 to 2010 (Table 6). In

2013 the high-density area was 20% of the standard DEPM survey area, which was much higher than in 2012 but lower than in previous years (e.g., 27% in 2009). The spawning area which was mostly located between Northern California in 2012 moved southward off Central and Southern California in 2013 (Figures 7 and 8). In previous years, such as 1999, 2004 and 2005, eggs were mostly concentrated north of Point Conception. Cooler water conditions in the California Current Ecosystem (CCE) may have influenced the movement of the spawning stock southward in the most recent years. Note that in the 2006 CCE survey, eggs were observed around latitudes 40°N to 43°N, which was not the case for the 2008 and the 2011 CCE surveys.

The adaptive allocation sampling procedure was used aboard the *Ocean Starr* and the *Shimada* (excluding Shimada data prior to April 23, see method section). A total of 106 CalVET tows were taken in the standard DEPM survey area. The number of tows was higher than in 2007 (n=84) and in 2005(n=74), but smaller than in most years (i.e., 124 in 2004, 123 in 2006, 217 in 2002, 192 in 2003, 151 in 2008, 136 in 2009, 129 in 2010, and 151 in 2011). Starting in 2011, adaptive sampling was used during the April CalCOFI survey. Even though in some years, such as 2012 and 2013, the data from CalCOFI survey may be partially used to compute the daily egg production (P_0), we still highly recommend that adaptive allocation sampling be applied during the spring (March-April) routine CalCOFI survey in the future to enhance the quality of the estimate of the spawning biomass.

Embryonic mortality curve

The estimates of the daily egg production at age 0 (P_0/0.05m^2 = 5.47 with CV = 0.29) and the daily embryonic mortality (0.64, CV = 0.16) from the mortality curve (Figure 6) in Region 1 were much higher than in recent years, i.e from 2007-2010. In many past years, the peak egg developmental stage was stage 6, whereas in 2012 the egg development stage peaked at stages 3 and 5 (Figure 3). Another extreme case was in 2010, when the peak densities spread from stage 6 to 9 (Lo et al. 2010b). The latter phenomenon is not understood and needs thorough investigation. However, in 2013 the egg development stage distribution was within expectation, with a single peak at stage 3. The overall P_0 in the DEPM (1.34 eggs/0.05m^2) was higher than in most previous years (Table 3 and 4), despite the relatively small size of the high density area (Figure 2). The yolk-sac larvae were mostly distributed between Monterey and Point Conception, with few positive net tows in the Southern California Bight (Figure 2). Note that yolk-sac larvae collected in Region 2 were not used in the computation of spawning biomass.

Catch ratio between CUFES and CalVET (E)

The 2013 catch ratio between CUFES and CalVET (0.1216) computed from data obtained from the *Ocean Starr* and *Bell M. Shimada* was higher than estimates from the last three years, 2012 (0.0338), 2011(0.058), and 2010 (0.077). This increase in catch ratio may suggest that relatively more eggs were the in upper 3m of the water column in 2013 than in most recent years. The 2013'catch ratio was similar to 2009 (0.15), 2008 (0.14), 2007 (0.15), 2005 (0.18), and 2001 (0.145), but was lower than that in 2006 (0.32), 2004 (0.22), 2003 (0.39), 2002 (0.24), 2000 (0.27), 1999 (0.34), 1998 (0.32), and 1996 (0.73). As these distribution patterns may be related to mixing in the water column, it would be informative to examine the relationship between the catch ratio and the degree of water mixing over the years (Lo et al. 2001).

The ratio of egg densities of two regions from pump samples (q)

The q value of 0.049 (CV = 0.346) (ratio of eggs/min in Region 2 to eggs/min in Region 1) (equation 2) was similar as in 2012, but lower than in 2011 (0.164 (CV = 0.23)) and other previous years for the standard DEPM sampling area. The q values have ranged from 0.036 to 0.085 in 2001-2006 with an increasing trend until 2011. The low q value indicated that the egg densities in Region 1 were much higher than in Region 2 and sardine eggs were more concentrated in Region 1 than Region 2. Otherwise the difference of densities of eggs between these two regions would be less.

Adult parameters

The April 2013 Sardine DEPM survey covered the standard DEPM area off California from San Francisco to San Diego, because little spawning occurred north of CalCOFI line 60 in recent coast-wide spring surveys, i.e. in 2006, 2008, and 2010-2012 (Lo et al. 2007a, 2008, 2010b, 2011, 2013) and ship time was limited. We examined the range of sea temperatures at 3m depth, recorded during trawl operations, in the standard DEPM area (Table 7). Although the highest average temperature with sardines present was in 2006 (14.4^{o}C) when some spawning did occur as far north as southern Oregon (Lo et al. 2007a), in 2013 sea temperature around trawls with sardines was the highest (13.65^{o}C) when compared to years since 2006 (Table 7). It is interesting to note that since 2008 the location of the high sardine egg density area (Region 1) occurred further south when the surveys extended past May 1st (Figure 7).

During the April 2013 survey in the standard DEPM survey area, we were again able to collect trawl samples (Table 2) in areas of high (Region 1) and low (Region 2) sardine egg densities which is beneficial to better estimate Pacific sardine spawning biomass for the whole population. We found that the average mature female weight (W_f) was similar in Region 1 (139.2 grams, SE = 4.75) and Region 2 (135.2 grams, SE = 4.84). This is similar to most of the recent years 2004-2012 when females in the regions were either similar in weight or slightly heavier in Region 1 (Table 8). The fraction of females spawning per day, S_{12}, (based on the average of females that spawned the night before capture and 2 night before capture or "average of day 1+day 2") was higher in Region 1 (0.161 females/day (CV = 0.21)) than Region 2 (0.129 females/day (CV = 0.18)) (Table 5) although the values are not significantly different (t = 0.77, p>0.2). This regional difference in the fraction of females spawning (high in 1 and lower in 2, Table 9) was similar to that in past DEPM surveys in 2005, 2006 (Lo and Macewicz 2006, Lo et al. 2007a), 2007 (when one unusual trawl is removed, Lo et al. 2007b), 2008, 2009, 2010, and 2011 (Lo et al. 2008, 2009, 2010b, 2011). Although there were more trawls conducted in Region 2 (49 trawls) than in Region 1 (21 trawls), most trawls taken in Region 2 failed to catch any sardines. In the future, we recommend reducing the extent of transect lines far offshore and we may reduce number of trawls in Region 2 when the egg density is zero or consistently less than 1 egg/min. However, because more females were spawning per day in Region 1 than Region 2, it is necessary to continue to trawl in both regions to ensure an unbiased estimate of spawning biomass for the whole population.

In 2013 the CV (0.16)) of the spawning fraction estimate in the DEPM area was similar to those in 2012 (CV = 0.24), 2011 (CV = 0.18), 2010 (CV = 0.22), and 2009 (CV = 0.15) but lower than in earlier years (CVs of 0.33 in 2007 and 0.31 in 2005 and 2008) (Lo et al. 2006, 2007b, 2008, 2009, 2010b, and 2011). The high CVs in the previous years were most likely due to the low number of sardine positive trawls (12-14) and high variance of spawning (Table 7). A factor in improvement of the CV was the change in the calculation of daily spawning fraction. In the past (1994, 1997, 2004, 2005, 2007, and 2008), calculation of the original daily spawning fraction (S_1) was based on the number of females that spawned the night before capture (night B, "day 1") and followed the procedure for northern anchovies (Picquelle and Hewitt, 1983) to replace the number of females spawning the night of capture (night C, "day 0") with the number of night B spawning females to adjust the number of total mature females. By contrast, since 2009 we calculated the daily spawning fraction (S_{12}) using the mean number of night-B and night-A (two nights before capture, "day 2") spawning females for each trawl and replaced the night-C females by this mean to adjust the number of total mature females. Therefore for continued improvement of spawning fraction precision, we recommend using S_{12} to calculate daily spawning fraction and that the number of trawls sampled be increased, in both high and low egg density areas, for future biomass surveys.

We examined the relative frequency of length by sex and the size-at-age of sardines collected in spring 2013 and compared them to length distributions and size-at-age of fish taken during similar periods in the standard DEPM area since 2008 (Figures 8 and 9). Although the mean size of sardines caught during 2013 (221 mm, male and females) was similar to 2012 (223 mm), the mean age increased to 3.64 years from 3.47 years (Table 9). No age-0 and only 1 age-1 fish were collected in 2013, and more sardine were older than 6 years compared to 2012. The length distribution in 2013 has a single size mode peaking at 220 mm, while 2012 showed two modes. The first mode in 2012 peaked about at 210 mm for both sexes, whereas the second mode peaked at 230 mm for males and 240 mm for females. Fish collected in 2011 had also a bi-modal distribution in their length and age. This change to one from two modes in 2012 and 2011 might be due to the increasing size of the recruits from 2009-2010 (Hill et al. 2012, Zwolinski et al. 2013) and few fish remaining from the strong recruitment class in 2003-2005. These strong recruitment years can also be seen in the size-at-age patterns in Figure 9. The 2003-2005 recruitment showed many 2-3 years old (about 215 mm) in 2008 to few 7-8-9 years old (about 245 mm) in 2013. The 2009-2010 recruitment showed many 1-2 years old (about 185 mm) in 2011 and many 3 years old (about 215 mm) in 2013. Another interesting pattern is that males tend to dominate the smaller sizes and younger ages while females dominate the larger and older classes. Finally, we believe that a likely explanation for the lack of smaller age-0 fish in 2012 and 2013 is poor recruitment of the recent year classes. It could possibly also be due to sampling issues, such as: 1) the lack of trawls positive for sardines inshore (Figure 7), where sardines are known to be small relative to offshore (Lo et al. 2007a); or 2) not conducting trawls in inshore areas that are known (because they have been commercially fished) to have sardines, e.g. around Catalina Island or the Channel Islands. We recommend that to improve the whole population adult parameter analyses more trawls should continue to be added in the inshore areas or samples taken on commercial vessels during fishing to obtain spawning and maturity information to avoid possible bias against smaller fish.

We did not estimate the size at which 50% of the female sardines were mature (ML_{50}) in 2013 because no immature females were caught. Considering that the smallest mature female in 2013 was 180 mm SL, it is possible that the size at ML_{50} in 2013 may be similar to the values in 2011 (186.47 mm) or 2004 (193 mm) and higher than the values in 2007, 2005, and 1994 (Figure 9). Dorval et al. (*In review*) have found no significant differences between size-at-maturity of Pacific cohorts born between 1986 and 2006, thus the variation in ML_{50} was not likely due to change in maturity. However, it may be the result of sample bias if any one of the following is true: 1) the trawls are located in a partial area of the survey (e.g., high egg density area only, offshore only, inshore or near islands only); 2) migration of sardine subpopulation occurred; and/or 3) the age and length relationship changed. We recommend continued evaluation of maturity to eliminate any biases.

Spawning biomass

In the DEPM survey area, the 2013 estimate of spawning biomass using the traditional method was 144,880 mt, based on the egg production of 1.34 eggs/0.05m^2/day, and the daily specific fecundity of 26.22 eggs/g/day. This production was mostly concentrated in two areas located between CalCOFI line 66.7 and 78.3 and between lines 85 and 91.7. The 2013 spawning biomass was lower than most previous estimates since 2004 except in 2008 and 2010 (Table 6). This estimate was based on the stratified sampling for each parameter because adequate female samples were available. As such it may not be comparable to estimates derived in years were not enough adult fish samples were collected (i.e. 2006, 1996-2003). In those years P_0 was weighted by the size of each region and the adult parameters were estimated from all trawl samples in the survey area.

The egg production rate in the high-density area, 5.47 eggs/0.05m^2, was similar to 2012 and 2011 but higher than estimates from 2008 to 2010 (Table 6). The overall daily egg production, 1.34 eggs/0.05m^2, is much higher than in most recent years: 0.36 eggs/0.05m^2/day in 2010, 0.59 in 2009, 0.43 in 2008, and 0.84 in 2012, and similar to that in 2011 (1.16), but lower than 1.936 in 2006, and 1.916 eggs/0.05m^2 in 2005.

Over the years, although the standard DEPM survey area has varied in size, it has been approximately between CalCOFI line 60 (near San Francisco) and line 95 (near San Diego). In 2013, the spawning biomass estimated in the standard DEPM area was considered to be the spawning biomass for the entire survey area (Figure 1). The region of high-egg density (29,176 km^2) was larger than 27,462 km^2 in 2010 and smaller than in other years. Note that the threshold of 1 egg/min was reduced from the number used in years prior to 2002 (2 eggs/min) to increase the area identified as the high-density area and, subsequently, to increase the number of CalVET samples. This adaptive allocation sampling was similar to that used in the 1997 survey (Lo et al. 2001). Because the threshold changed in 2002, caution should be taken when comparing the size of the area of Region 1.

The adult daily reproductive output (daily specific fecundity) was the largest recorded since 2004. However, the higher values in early years were due to the fact that trawl samples were taken in the high-density area only. Since 2005, trawl samples have been taken in both Region 1 and Region 2.

For the stock assessment we provided the estimates of female spawning biomass for years where adequate adult samples were available (Table 6).

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Table 1. Number of positive tows of sardine eggs from CalVET, yolk-sac larvae from CalVET and Bongo, eggs from CUFES and positive sardine trawls[a] in Region 1 (eggs/min ≥ 1), Region 2 (eggs/min < 1) for *Ocean Starr* and *Bell M. Shimada*[b] cruises of 2013 April Sardine DEPM survey. Both *Shimada* and *Ocean Starr* occupied part of the standard DEPM survey area. *Shimada* occupied the area from Avila Beach to Half Moon Bay, California (CalCOFI line 76.7 to 63.3). *Ocean Starr* occupied the area from just south of Monterey Bay, California to Oceanside, California (CalCOFI line 68.3 to 91.7).

		Region 1	**Region 2**	**Grand Total**
CalVET Eggs	Positive	32	17	49
	Total	40	66	106
CalVET Yolk-sac	Positive	11	8	19
	Total	40	66	106
Bongo Yolk-sac	Positive	9	-	9
	Total	12	51	63
CUFES Eggs	Positive	82	73	155
	Total	95	296	391
Trawls	Positive	11	7	18
	Total	21	49	70

[a] All sardines were captured at night.
[b] only data collected during the DEPM portion (April 23-April 30) of the *Shimada* cruise is included in the table.

Table 2. Sardine egg density region, individual trawl information, sex ratio[a], and parameters for mature female *Sardinops sagax*, used in the estimation of the April 2013 spawning biomass in the standard DEPM sampling area off California.

COLLECTION INFORMATION									MATURE FEMALES							
				Location										Number spawning		
Region 1=high 2=low	No.	Month-Day	Time	Latitude °N	Longitude °W	Surface Temp. °C	No. of fish	Sex Ratio	No. analyzed	Body weight (g) Ave.	Weight without ovary (g) Ave.	Batch Fecundity Ave.	Adj. No.[b]	Night of capture	Night before capture	2 Nights before capture
1	2943	4-18	00:42	35.048	-123.686	12.5	1[c]	0.000	0	0	0	0	0.0	0	0	0
1	2951	4-21	00:41	34.764	-122.310	12.7	40	0.410	16	128.85	121.79	37409	5.5	11	1	0
1	2953	4-21	23:12	34.893	-122.831	12.5	8	0.546	4	147.31	136.80	46139	1.0	3	0	0
1	2954	4-22	1:25	34.960	-122.671	12.5	50	0.492	25	130.39	123.18	39385	11.5	15	2	1
1	2962	4-24	22:23	34.621	-121.725	13.2	18	0.809	14	158.82	147.90	47147	17.5	0	5	2
1	2963	4-25	00:30	34.721	-121.862	13.3	11	0.842	9	142.77	134.74	42052	11.0	1	3	3
1	2976	4-29	19:42	33.252	-119.996	13.4	3	0.366	1	157.32	147.87	46919	0.0	1	0	0
1	2977	4-29	22:58	33.037	-119.963	13.2	4[c]	0.000	0	0	0	0	0.0	0	0	0
1	2979	4-30	20:17	33.559	-118.473	17.1	34	0.645	19	141.51	132.67	42656	8.5	11	0	1
2	2980	4-30	22:51	33.630	-118.710	16.5	3	0.354	1	111.00	105.24	26176	1.0	0	0	0
2	2981	5-01	2:11	33.594	-118.628	16.7	8	0.906	7	138.86	131.28	43967	6.5	1	0	1
1	2989	5-03	20:03	33.193	-117.574	18.2	1	1.000	1	128.50	118.77	30657	1.0	0	0	0
1	3061	4-24	20:10	35.395	-123.428	12.5	3[c]	0.000	0	0	0	0	0.0	0	0	0
2	3063	4-25	1:18	35.501	-123.751	12.4	6	0.670	4	119.13	114.89	34743	4.0	1	1	1
2	3065	4-25	23:36	35.371	-124.277	12.1	14	0.585	8	129.38	118.89	32840	8.0	1	1	1
2	3066	4-26	2:23	35.513	-124.407	12.9	2	0.504	1	121.00	115.09	21078	0.0	1	0	0
2	3070	4-27	20:13	36.449	-123.673	12.5	9	0.700	6	137.05	128.47	43298	5.5	1	0	1
2	3073	4-28	20:20	36.802	-123.761	11.5	10	0.509	5	157.70	146.91	58238	6.0	0	0	2
all									121				87	47	13	13

[a] Sex ratio, proportion of females by weight, based on average weights from subsamples and number of fish sampled in each trawl(Picquelle and Stauffer 1985).
[b] Mature adjusted by the average number of females spawning the night before capture and females spawning 2 nights before capture
[c] Only male(s) captured

Table 3. Egg production (P_0) of the Pacific sardine in 2013 based on egg data from CalVET and yolk-sac larval data from CalVET and Bongo in Region 1 (eggs/min ≥ 1) and Region 2 (eggs/min < 1) from *Ocean Starr* (April 8 – May 3), and *Shimada* (April 23 – 30) cruises, adult parameters from positive trawls (April 18 – May 3), and 2013 spawning biomass estimates.

Parameter	Region 1	Region 2	DEPM Area
CUFES samples	95	296	**391**
CalVET samples	40	66	**106**
P_0 / 0.05m^2	5.47[a]	0.27	**1.34**
CV of P_0	0.29	0.44	**0.299**
Area (km^2)	29176	112221	**141397**
% of DEPM Area	21	79	100
Year of adult samples	2013	2013	2013
Female fish wt (W_f)	139.25	135.2	**138.17**
Batch fecundity (F)	41509	40865	**41339**
Spawning fraction (S)	0.161	0.129	**0.149**
Sex ratio (R)	0.572	0.633	**0.586**
(RSF)/W_f	27.41	24.71	**26.22**
Spawning biomass (mt) :*Tradional method* [b]			**144,880**
CV of spawning biomass			**0.36**
Spawning biomass (mt) : *Stratified procedure* [c]	116,455	24,547	**141,002**
CV of spawning biomass	0.40	0.48	**0.34**
Daily mortality (*Z*)			**0.64**
CV of daily mortality			**0.16**
eggs/min	2.178	0.094	**0.54**
CV	0.19	0.44	**0.17**
q = eggs/min in Reg.2 / eggs/min in Reg.1			**0.049**
CV of q			**0.35**
E = (eggs/min)/(eggs/tow)			**0.1527**
CV			**0.22**
Bongo samples	12	51	**63**

[a] 5.47 was corrected for bias of P_0.
[b] biomass was computed from estimates of parameters in each column, e.g., DEPM area is an average of adult parameters from Region 1 and DEPM Region 2.
[c]biomass was computed by the stratified procedure, i.e., total spawning biomass = the sum of the estimates of spawning biomass in Region 1 and Region 2: 116,455 + 24,547 = 141,002

Table 4. Estimates of daily egg production (P_0)[a] for the DEPM survey area, daily instantaneous mortality rates (Z) from high-density area (Region 1), daily specific fecundity (RSF/W), spawning biomass of Pacific sardines using the traditional method (which differs from the stratified method) and average sea surface temperature for the years 1994 to 2012.

Year	P_0 (CV)	Z (CV)	Area (km^2) (Region 1)	RSF[h]/W	Spawning biomass (mt) (CV)[b]	Mean Temp. for positive egg or yolk-sac samples	Mean temperature all CalVETs
1994	0.193 (0.210)	0.120 (0.91)	380,175 (174,880)	11.38	127,102 (0.32)	14.3	14.7
1995	0.830 (05)	0.400 (0.4)	113,188.9 (113188.9)	23.55[c]	79,997 (0.6)	15.5	14.7
1996	0.415 (0.42)	0.105 (4.15)	235,960 (112,322)	23.55	83,176 (0.48)	14.5	15.0
1997	2.770 (0.21)	0.350 (0.14)	174,096 (66,841)	23.55[d]	409,579 (0.31)	13.7	13.9
1998	2.279 (0.34)	0.255 (0.37)	162,253 (162,253)	23.55	313,986 (0.41)	14.38	14.6
1999	1.092 (0.35)	0.100 (0.6)	304,191 (130,890)	23.55	282,248 (0.42)	12.5	12.6
2000	4.235 (0.4)	0.420 (0.73)	295,759 (57,525)	23.55	1,063,837 (0.67)	14.1	14.4
2001	2.898 (0.39)	0.370 (0.21)	321,386 (70,148)	23.55	790,925 (0.45)	13.3	13.2
2002	0.728 (0.17)	0.400 (0.15)	325,082 (88,403)	22.94	206,333 (0.35)	13.6	13.6
2003	1.520 (0.18)	0.480 (0.08)	365,906 (82,578)	22.94	485,121 (0.36)	13.7	13.8
2004	0.960 (0.24)	0.250 (0.04)	320,620 (68,234)	21.86[e]	281,639 (0.3)	13.4	13.7
2005	1.916 (0.417)	0.579 (0.20)	253,620 (46,203)	15.67	621,657 (0.54)	14.21	14.1
2006	1.936 (0.256)	0.31 (0.25)	336,774 (98,034)	15.57[f]	837,501[f] (0.46)	14.95	14.5
2007	0.864 (0.256)	0.133 (0.36)	356,159 (142,403)	15.68	392,492 (0.45)	13.7	13.6
2008[g]	0.43 (0.21)	0.13 (0.29)	297,949 (53,514)	21.82	117,426 (0.43)	13.3	13.1
2009[h]	0.59 (0.22)	0.25 (0.19)	274895 (74,966)	17.53	185,084 (0.28)	13.6	13.5
2010[i]	0.36 (0.40)	0.33 (0.23)	271,773 (27,462)	18.07	108,280 (0.46)	13.7	13.9
2011	1.16 (0.26)	0.51 (0.14)	314,481 (41,878)	19.04	383,286 (0.32)	13.5	13.6
2012	0.84 (0.27)	0.66 (0.11)	270,991 (32,322)	16.14	282,110 (0.43)	13.57	13.3
2013	1.34 (0.30)	0.64 (0.16)	141,397 (29,176)	26.22	144,880 (0.36)	13.51	13.47

a weighted non-linear regression on original data and bias correction of 1.04, except in 1994 and 1997 when grouped data and a correction factor of 1.14 was used (appendix Lo 2001).

b $CV(B_s) = (CV^2(P_0) + allotherCOV^2)^{1/2} = (CV^2(P_0)+0.054)^{1/2}$. For years 1995 – 2001 allotherCOV^2 was from 1994 data (Lo et al. 1996). For year 2003, allotherCOV was from 2002 data (Lo and Macewicz 2002)

c 23.55 was from computation for 1994 based on S = 0.149 (the average spawning fraction (day 0 + day 1) of active females from 1986–1994; Macewicz et al. 1996).

d is 25.94 when calculated from parameters in 1997 (table 9) and estimated spawning biomass is 371,725 mt with CV = 0.36

e uses R = 0.5 (Lo and Macewicz 2004); if use actual R = 0.618, then value is 27.0 and biomass is estimated at 227,746 mt

f value for standard DEPM sampling area off California when calculated using S = 0.126, the average of females spawning the night before capture ("day 1") from 1997, 2004, 2005, and 2007. When 2006 survey S of 0.0698 was previously used (Lo et al. 2007a), the 2006 DEPM spawning biomass was estimated as 1,512,882 mt (CV 0.46) and the 2006 coast-wide spawning biomass was estimated as 1,682,260 mt

g standard DEPM sampling area off California from San Diego to CalCOFI line 66.7 whole 2008 survey area off west coast of North America from about 31°N to 48.47°N latitude, spawning biomass was estimated as 135,301 mt(CV=0.43)

h RSF/W from 2009 forward is based on S_{12},:average of day1 and day2 females.

i The whole survey area was 477,092 km^2 from San Diego, CA to Cape Flattery, Wa. .Very few sardine eggs were observed north of the DEPM survey area (CalCOFI line 60.0 is the northern boundary of the DEPM area)

Table 5. Estimated 2013 adult parameters and correlations for each region[a] in the DEPM area outputted from the EPM program (Appendix II Chen et al. 2003).

Region 1 DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	139.25230436	22.5291038021
Gonad Fee Weight	130.852926966	17.0576442645
Batch fecundity	41508.7836436	5758697.48172
Spawners, Day 0	0.47191011236	0.01186303089
Spawners ave (day1+day2)	0.16071433929	0.00111560042
Sex Ratio	0.5721804325	0.00382736806
Daily specific fecundity	27.4110230852	
Number of Sets	8	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.97638402	0.47419187	0.89347324
Batch Fecundity (F)			0.40022077	0.91088864
Fraction Spawning (S)				0.50614020
Sex Ratio (R)				

Region 2 DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	135.196326875	23.3889214423
Gonad Fee Weight	126.729690625	20.5881702021
Batch fecundity	40865.4875579	18767477.2164
Spawners, Day 0	0.15625	0.00178019206
Spawners ave (day1+day2)	0.12903229032	0.00056026699
Sex Ratio	0.63344366901	0.00363255987
Daily specific fecundity	24.7057588642	
Number of Sets	7	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.94061544	-0.1241272	-0.1530126
Batch Fecundity (F)			0.01664589	-0.0540405
Fraction Spawning (S)				-0.5102715
Sex Ratio (R)				

DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	138.179649157	12.6306519844
Gonad Fee Weight	129.762484298	9.77608904461
Batch fecundity	41338.6557532	6267914.45836
Spawners, Day 0	0.38842975207	0.00850095739
Spawners ave (day1+day2)	0.14942533333	0.00056206537
Sex Ratio	0.58649756973	0.00246238617
Daily specific fecundity	26.2181905	
Number of Sets	15	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.88160305	0.41900976	0.77133952
Batch Fecundity (F)			0.27813481	0.60838107
Fraction Spawning (S)				0.39229254
Sex Ratio (R)				

[a] Area of Region 1 is 29,176 km^2, Region 2 area is 112,221 km^2, and the total DEPM area is 141,397 km^2

Table 6. The spawning biomass related parameters using the stratified method: daily egg production/0.05m^2 (P_0),daily mortality rate (z), survey area (km^2), two daily specific fecundities: (RSF/W), and (SF/W); s. biomass, female spawning biomass, total egg production (TEP) and sea surface temperature for 1986, 1987, 1994, 2004, 2005 and 2007-2013.

Calendar year	Season	Region	[1]P_0/0.05m^2 (cv)	*Z* (CV)	[2]RSF/W based on S_1	[3]RSF/Wb ased on S_{12}	[3]FS/W based on S_{12}	[4]Area (km^2)	[5]S. biomass (cv)	S. biomass females (cv)	S. biomass females (Sum of R1andR2) (cv)	Total egg production (TEP)	Mean temper-ature (°C) for positive eggs	Mean temper-ature (°C) from Calvet
1986(Aug)	1986	[6]S	1.48(1)	1.59(0.5)	38.31	43.96	72.84	6478	4362 (1.00)	2632 (1)		9587.44		
		N	0.32(0.25)		8.9	13.34	23.89	5333	2558 (0.33)	1429 (0.28)		1706.56		
		whole	0.95(0.84)		23.61	29.89	49.97	11811	7767 (0.87)	4491 (0.86)	4061 (0.66)	11220.45	18.7	18.5
1987(Jul)	1987	1	1.11(0.51)	0.66(0.4)	38.79	37.86	57.05	22259	13050 (0.58)	8661 (0.56)		24707.49		
		2	0					15443	0	0		0		
		whole	0.66(0.51)		38.79	37.86	57.05	37702	13143 (0.58)	8723 (0.56)	8661 (0.56)	25637.36	18.9	18.1
1994	1993	1	0.42(0.21)	0.12(0.91)	11.57	11.42	21.27	174880	128664 (0.30)	69065 (0.30)		73449.6		
		2	0(0)	-				205295	0	0		0		
		whole	0.193(0.21)		11.57	11.42	21.27	380175	128531 (0.31)	68994 (0.30)	69065 (0.30)	73373.775	14.3	14.7
2004	2003	1	3.92(0.23)	0.25(0.04)	27.03	26.2	42.37	68204	204118 (0.27)	126209 (0.26)		267359.68		
		2	0.16(0.43)		-	-	-	252416	30833 (0.45)	19065 (0.44)		40386.56		
		whole	0.96(0.24)		27.03	26.2	42.37	320620	234958 (0.28)	145297 (0.27)	145274 (0.23)	307795.2	13.4	13.7
2005	2004	1	8.14(0.4)	0.58(0.2)	31.49	25.6	46.52	46203	293863 (0.45)	161685 (0.42)		376092.42		
		2	0.53(0.69)		3.76	3.2	7.37	207417	686168 (0.86)	298258 (0.89)		109931.01		
		whole	1.92(0.42)		15.67	12.89	27.11	253620	755657 (0.52)	359209 (0.50)	459943 (0.60)	486950.4	14.21	14.1
2007	2006	1	1.32(0.2)	0.13(0.36)	12.06	13.37	27.54	142403	281128 (0.42)	136485 (0.36)		187971.96		
		2	0.56(0.46)		24.48	23.41	38.94	213756	102998 (0.67)	61919 (0.62)		119703.36		
		whole	0.86(0.26)		15.68	16.17	31.52	356159	380601 (0.39)	195279 (0.36)	198404 (0.31)	306296.74	13.7	13.6
2008	2007	1	1.45(0.18)	0.13(0.29)	57.4	53.89	68.54	53514	29798 (0.20)	22642 (0.19)		77595.3		
		2	0.202(0.32)		13.84	12.6	22.57	244435	78359 (0.45)	43753 (0.42)		49375.87		
		whole	0.43(0.21)		21.82	20.31	32.2	297949	126148 (0.40)	79576 (0.35)	66395 (0.28)	128118.07	13.1	13.1
2009	2008	1	1.76(0.22)	0.25(0.19)	19.50	20.37	36.12	74966	129520 (0.31)	73048 (0.29)		131940.16		
		2	0.15(0.27)		14.25	14.34	22.97	199929	41816 (0.38)	26114 (0.38)		29989.35		
		whole	0.59(0.22)		17.01	17.53	29.11	274895	185084 (0.28)	111444 (0.27)	99162 (0.24)	162188.05	13.6	13.5

continue Table 6

Calendar year	Season	Region	P0/0.05m2 (cv)	Z (CV)	RSF/W based on S_1	RSF/W based on S_{12}	FS/W based on S_{12}	Area (km^2)	S. biomass (cv)	S. biomass females (cv)	S. biomass females (Sum of R1andR2) (cv)	Total egg production (TEP)	Mean temper-ature (°C) for positive eggs	Mean temper-ature (°C) from Calvet
2010	2009	1	1.70(0.22)	0.33(0.23)	21.08	24.02	51.56	27462	38875 (0.44)	18111 (0.39)		46685.4		
		2	0.22(0.42)		14.55	16.20	26.65	244311	66345 (0.58)	40336 (0.58)		53748.42		
		whole	0.36(0.29)		16.08	18.07	31.49	271773	108280 (0.46)	62131 (0.46)	58447 (0.42)	97838.28	13.7	13.9
2011	2010	1	5.57(0.24)	0.51(0.14)	19.03	24.26	41.16	41878	192332 (0.31)	113340 (0.30)		233260.5		
		2	0.487(0.33)		11.40	14.67	25.04	272603	181016 (0.48)	106046 (0.49)		132757.7		
		whole	1.16(0.26)		14.85	19.04	32.40	314481	383286 (0.32)	225155 (0.32)	219386 (0.28)	364798.0	13.5	13.6
2012	2011	1	5.28 (0.27)	0.66(0.11)	17.76	19.25	42.17	32322	177289 (0.37)	80930 (0.33)		170660.16		
		2	0.24 (0.27)		15.34	14.67	35.52	238669	78102 (0.60)	32248 (0.46)		57280.56		
		whole	0.84 (0.27)		16.14	16.14	37.65	270991	282110 (0.43)	120902 (0.36)	113178 (0.27)	227632.44	13.57	13.3
2013	2012	1	5.47 (0.29)	0.64(0.16)	32.35	27.41	47.91	29176	116455 (0.40)	66633 (0.36)		159592.72		
		2	0.27 (0.44)		13.20	24.71	39.00	112221	24547 (0.48)	15549 (0.49)		30299.67		
		whole	1.34 (0.299)		26.22	26.22	44.70	141397	144880 (0.36)	84972 (0.33)	82182 (0.30)	198471.98	13.51	13.47

1: P_0 for the whole is the weighted average with area as the weight.

2. The estimates of adult parameters for the whole area were unstratified and RSF/W was based on original S_1 data of day-1 spawning females. For 2004, 27.03 was based on sex ratio= 0.618 while past biomass used RSF/W of 21.86 based on sex ratio = 0.5.(Lo et al. 2008)

3. The estimates of adult parameters for the whole area were unstratified. Batch fecundity was estimated with error term. For 1987 and 1994, estimates were based on S_1 using data of day-1 spawning females. For 2004, all trawls were in region 1 and value was applied to region 2,

4. Region 1, since 1997, is the area where the eggs/min from CUFES ≥1 and prior to 1997, is the area where the eggs/0.05m^2 >0 from CalVET tows

5: For the spawning biomasses, the estimates for the whole area uses unstratified adult parameters

6. Within southern and northern area, the survey area was stratified as Region 1 (eggs/0.05m2>0 with embedded zero) and Region 2 (zero eggs)

Table 7. Pacific sardine female adult parameters for surveys conducted in the standard daily egg production method (DEPM) sampling area off California (1994 includes females from off Mexico).

		1994	1997	2001	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Midpoint date of trawl survey		22-Apr	25-Mar	1-May	21-Apr	25-Apr	13-Apr	2-May	24-Apr	16-Apr	27-Apr	20-Apr	8-Apr	19-Apr	25-Apr
Beginning and ending dates of positive collections		04/15-05/07	03/12-04/06	05/01-05/02	04/18-04/23	04/22-04/27	03/31-04/24	05/01-05/07	04/19-04/30	04/13-04/27	04/17-05/06	04/12-04/27	03/23-04/25	04/08-04/28	04/18-05/03
N collections with mature females		37	4	2	6	16	14	7	14	12	29	17	30	16	15
N collection within Region 1		19	4	2	6	16	6	2	8	4	15	3	14	8	8
Average surface temperature (°C) at collection locations		14.36	14.28	12.95	12.75	13.59	14.18	14.43	13.6	12.4	12.93	13.62	13.12	13.18	13.65
Female fraction by weight	**R**	0.538	0.592	0.677	0.385	0.618	0.469	0.451	0.515	0.631	0.602	0.574	0.587	0.429	0.586
Average mature female weight (grams): with ovary	**W_f**	82.53	127.76	79.08	159.25	166.99	65.34	67.41	81.62	102.21	112.40	129.51	127.59	141.36	138.17
without ovary	**W_{of}**	79.33	119.64	75.17	147.86	156.29	63.11	64.32	77.93	97.67	106.93	121.34	119.38	131.58	129.76
Average batch fecundity[a] (mature females, oocytes)	**F**	24283	42002	22456	54403	55711	17662	18474	21760	29802	29790	39304	38369	38681	41339
Relative batch fecundity (oocytes/g)		294	329	284	342	334	270	274	267	292	265	303	301	274	298
N mature females analyzed		583	77	9	23	290	175	86	203	187	467	313	244	126	121
N active mature females		327	77	9	23	290	148	72	187	177	463	310	244	125	119
Spawning fraction of mature females[b]	**S**	0.074	0.133	0.111	0.174	0.131	0.124	0.0698	0.114	0.1186	0.1098	0.1038	0.1078	0.1376	0.149
Spawning fraction of active females[c]	**S_a**	0.131	0.133	0.111	0.174	0.131	0.155	0.083	0.134	0.1187	0.1108	0.1048	0.1078	0.1388	0.153
Daily specific fecundity	**$\frac{RSF}{W}$**	11.7	25.94	21.3	22.91	27.04	15.67	8.62	15.68	21.82	17.53	18.07	19.04	16.14	26.22

[a] 1994-2001 estimates were calculated using F_b = -10858 + 439.53 W_{of} (Macewicz et al. 1996), 2004 used F_b = 356.46W_{of}. (Lo and Macewicz 2004), 2005 used F_b = -6085 + 376.28 W_{of} (Lo and Macewicz 2006), 2006 used F_b = -396 + 293.39 W_{of} (Lo et al. 2007a), 2007 used F_b = 279.23W_{of} (Lo et al. 2007b), 2008 used F_b = 305.14W_{of} (Lo et al. 2008), 2009 used F_b = -4598 + 326.78W_{of} + e (Lo et al. 2009), 2010 used F_b = 5136 + 287.37W_{of} + e (Lo et al. 2010), 2011 used F_b = -2252 + 347.6W_{of} + e (Lo et al. 2011), and 2012 used F_b = -12724 + 402.3W_{of} + e (Lo et al. 2013).

[b] Mature females include females that are active and those that are postbreeding (incapable of further spawning this season). S_1 was used for years prior to 2009 and S_{12} was used staring 2009.

[c] Active mature females are capable of spawning and have ovaries containing oocytes with yolk or postovulatory follicles less than 60 hours old.

Table 8. Trawl and mature Pacific sardine female biological data in each sardine egg density region (1 = high, 2 = low) of the DEPM area for surveys conducted 2004-2013.

Survey year and regions	Trawls			Mature Females			
	Sex Ratio	Mean Sea Temp (°C)	Number with Mature Females (total trawls)	Number	Mean Weight (g, W_f)	Relative Batch Fecundity[a]	Daily Spawning Fraction (S)[b]
2013							
1	0.572	13.7	8 (21)	89	139.25	298.09	0.161
2	0.663	13.5	7 (49)	32	135.20	302.26	0.129
2012							
1	0.456	13.0	8 (16)	48	131.08	264.55	0.159
2	0.412	13.4	8 (76)	78	147.69	278.60	0.128[c]
2011							
1	0.589	13.4	14 (22)	115	128.36	302.31	0.136
2	0.586	12.9	16 (78)	129	126.92	299.25	0.084
2010							
1	0.466	13.1	3 (11)	60	133.58	311.78	0.165
2	0.608	13.7	14 (58)	253	128.54	301.45	0.088
2009							
1	0.564	13.2	15 (21)	196	94.35	256.87	0.141
2	0.624	12.7	14 (40)	271	125.5	269.37	0.085
2008							
1	0.786	13.2	4 (11)	53	107.32	292.02	0.250
2	0.558	12.1	8 (18)	134	100.20	291.36	0.085
2007							
1	0.488	13.1	8 (10)	136	86.2	266.0	0.093
2	0.615	13.6	6 (8)	67	69.1	268.8	0.151[d]
2006							
1	0.465	14.8	2 (8)	20	74.35	271.79	0.100
2	0.447	14.3	5 (14)	66	65.30	274.87	0.061
2005							
1	0.550	14.7	6 (8)	80	67.02	269.05	0.213
2	0.425	13.8	8 (11)	95	63.93	272.79	0.033
2004							
1	0.618	13.6	16 (24)	290	166.99	333.62	0.131
2	--	--	0	--	--	--	--

[a] oocytes in batch to be spawned per gram of mature female weight
[b] 2006 and 2009-2012 was estimated based on the mean number of females which on two different nights, while 2004, 2005, and 2007 was based on females which had spawned on the night before capture only
[c] fraction is 0.067 without 1 trawl with a high number of spawning females (7 of 25)
[d] fraction is 0.044 without 1 trawl with a high number of spawning females (10 of 22)

Table 9. Range in latitude and temperature (3m depth) of trawls, and mean weight, length and age of Pacific sardine adults (male and female) taken during the spring 2008-2013 surveys off California within the standard DEPM area (CalCOFI lines 60 – 95, San Francisco to San Diego).

Survey Information	**April 2008**	**April 2009**	**April 2010**	**April 2011**	**April 2012**	**April 2013**
Sea temperature range	11.2-15.5°C	9.4-16.2	12.1-15.9°C	9.9-16.4°C	9.9-15.7°C	10.1-18.2
Mean °C of sardine positive trawls	12.4°C	13.2	13.6°C	13.1°C	13.2	13.6
Number positive trawls (total)	13 (31)	34(61)	18 (69)	36 (100)	20 (92)	18 (70)
Number sardine in random sample	353	957	635	666	264	225
Number of sardine aged	351	918	623	626	263	216
Mean body weight (g)	105g	111g	127g	108g	134g	137g
Mean standard length (mm)	211	212	219	205	223	221
Mean age (years)	3.00	3.53	3.99	2.93	3.47	3.62
Age range	1 to 5	0 to 6	0 to 7	0 to 7	1 to 7	1 to 9

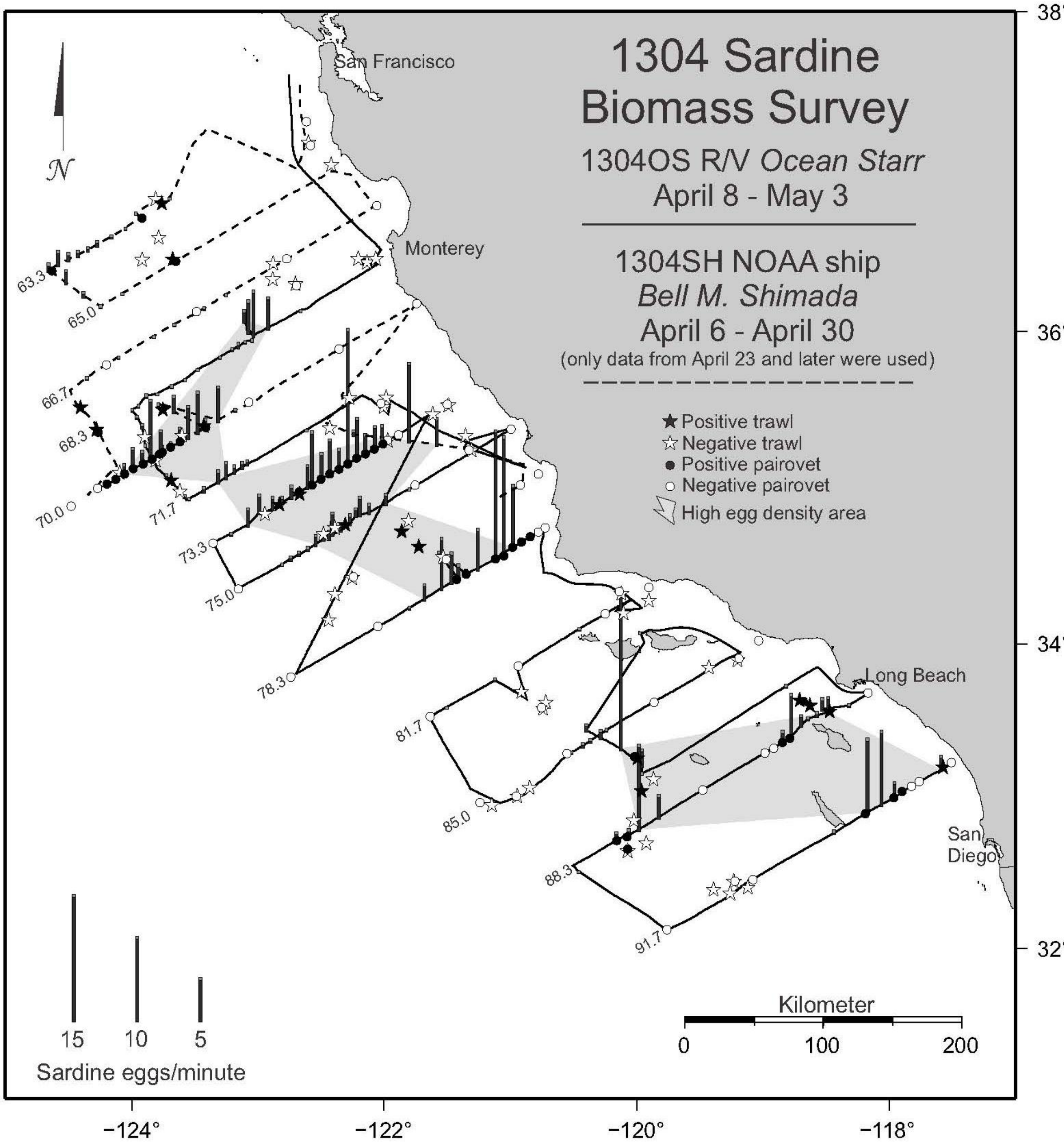

Figure 1. DEPM standard area and location of sardine eggs collected from CalVET, a.k.a. Pairovet; (solid circle is a positive catch and open circle is zero catch) and from CUFES (stick denotes positive collection), and trawl locations (solid star is catch with sardine adults and open star is catch without sardines) during the 2013 survey aboard two vessels: the R/V *Ocean Starr* (dash line) and the NOAA ship *Bell M. Shimada* (solid line). Shaded area is Region 1, the high egg-density area, and the rest of survey area is Region 2.

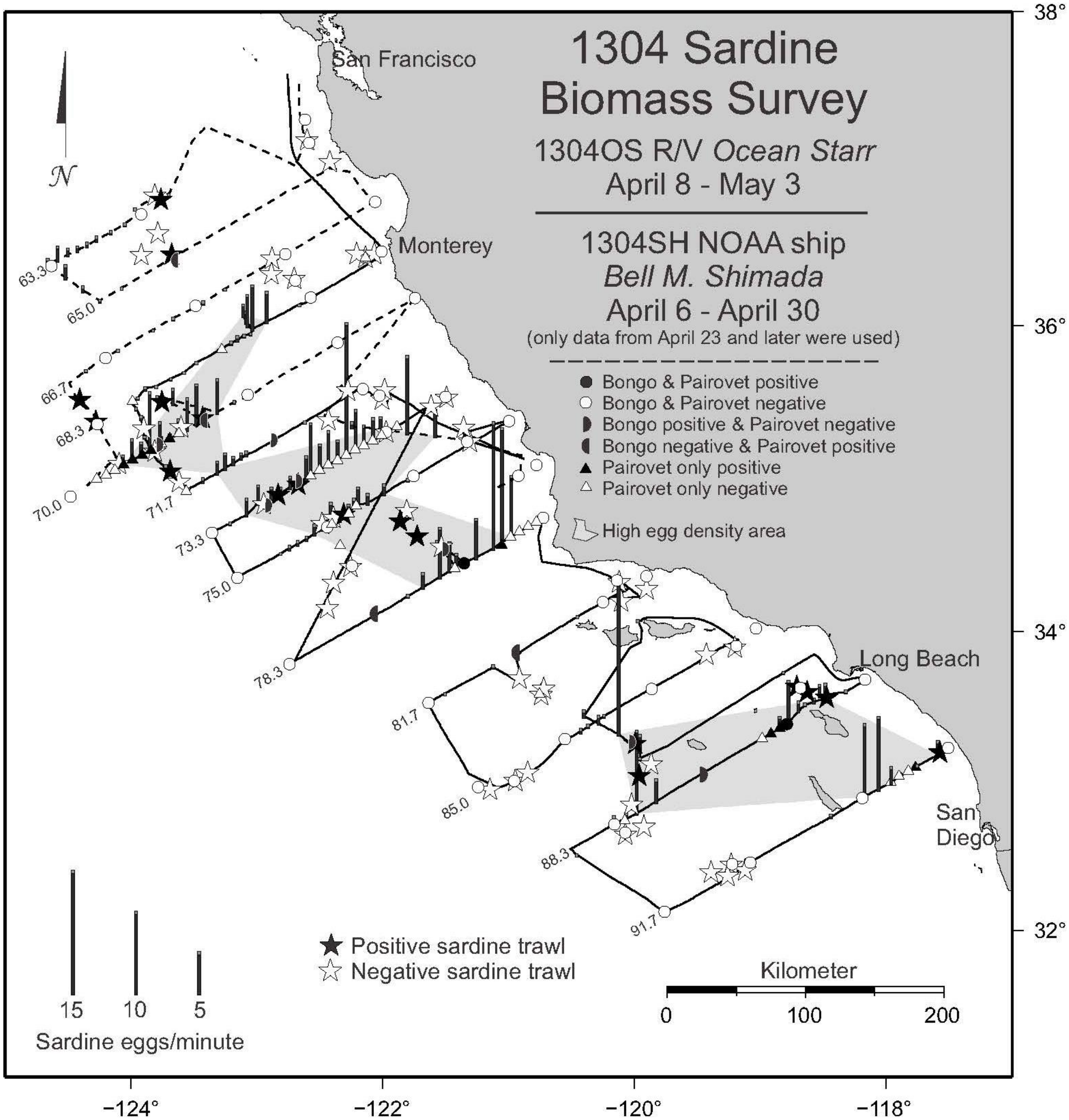

Figure 2. Location of sardine trawls (star), yolk-sac larvae collected from CalVET (or Pairovet; circle and triangle) and from Bongo (circle and semi-circle) during the 2013 survey aboard two vessels: the R/V *Ocean Starr* (solid line) and the NOAA ship *Bell M. Shimada* (dash line). Solid symbols are positive and open symbols are zero catch. The shaded area is Region 1: the high egg-density area. Region 2 in the standard DEPM area includes survey area shown between CalCOFI line 91.7 and 63.3.

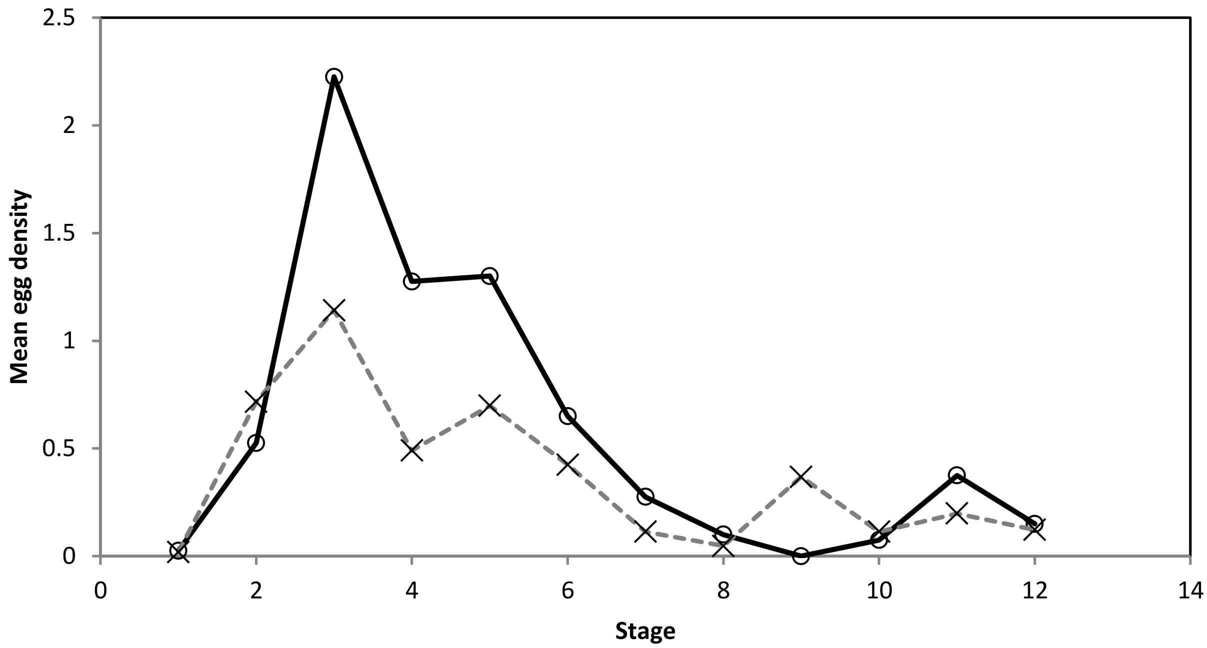

Figure 3. Mean sardine egg density (eggs per $0.05m^2$) for each developmental stage within the high density region (o = Region 1) and the whole DEPM survey area (CalCOFI lines 90 to 60, symbol X) for April 2013.

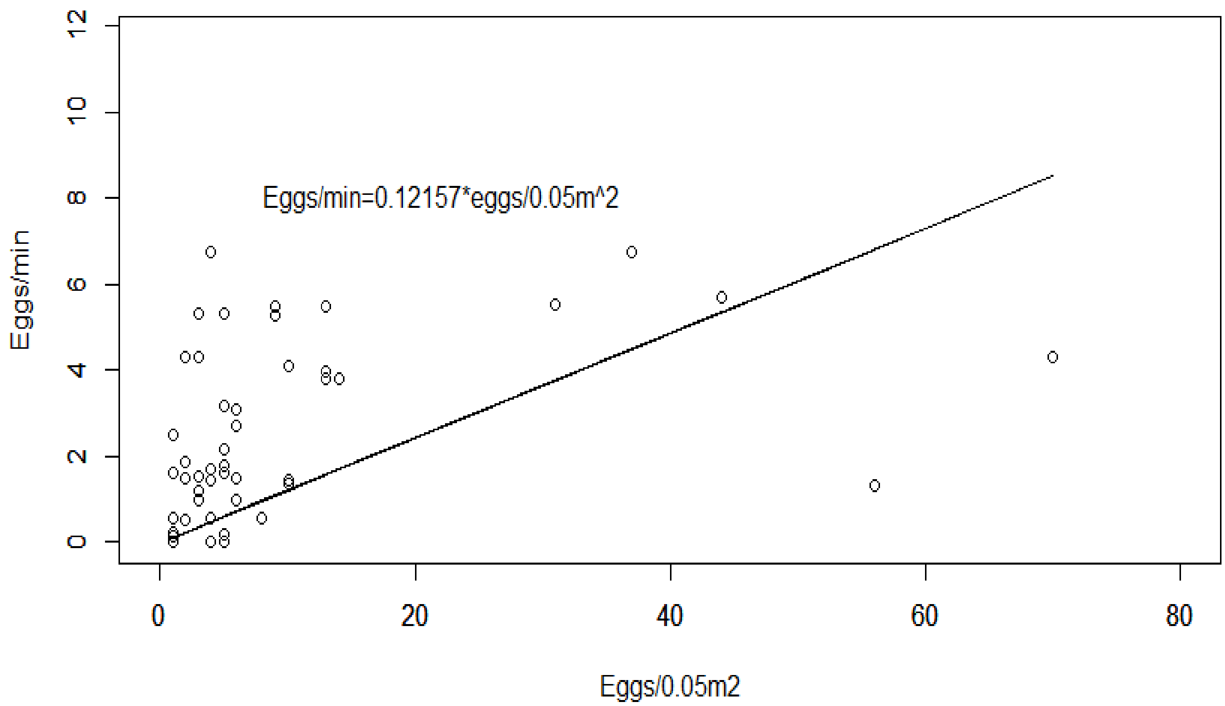

Figure 4. Catch ratio of eggs/min from CUFES to eggs/0.05m^2 from CalVET during April 2013 from *Ocean Starr* and *Shimada* collections.

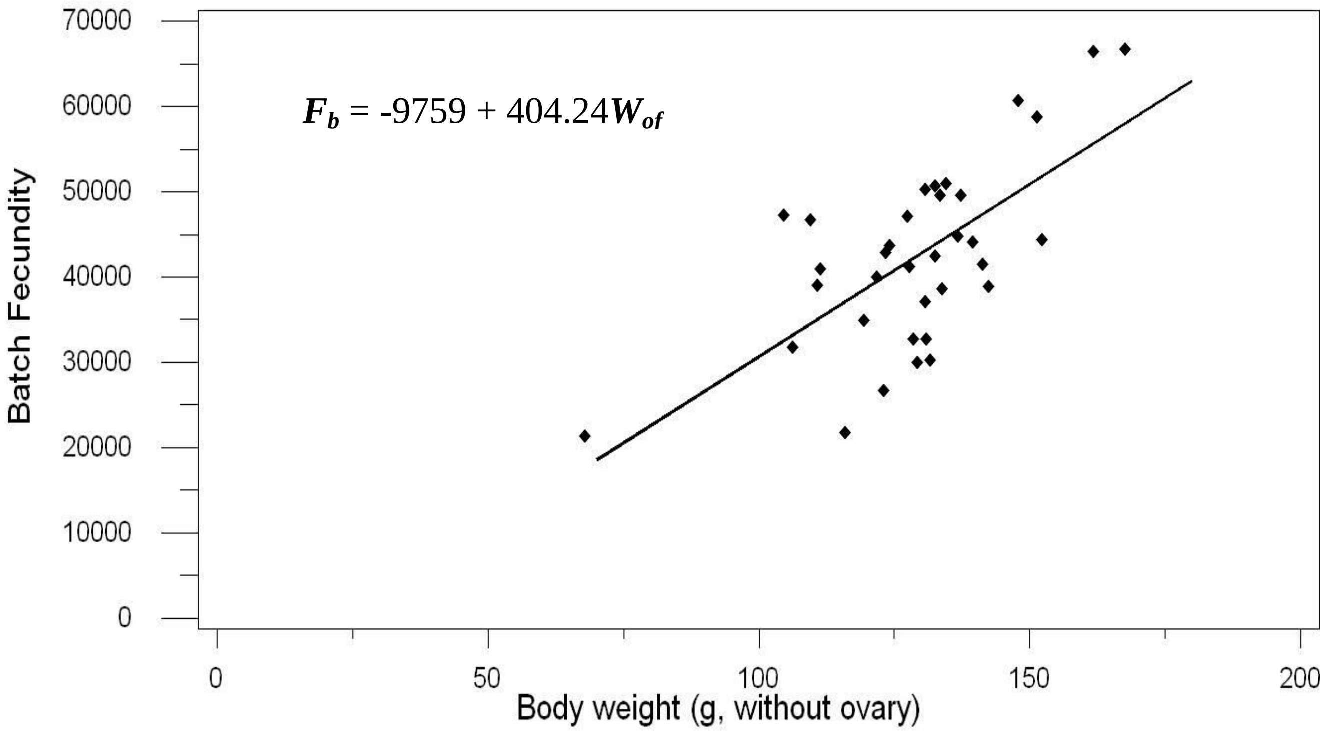

Figure 5. Batch fecundity (F_b) of *Sardinops sagax* as a function of female body weight (W_{of}, without the ovary) for 35 females taken onboard the *Bell M. Shimada* and *Ocean Starr* during April 2013. The batch was estimated from the number of hydrated or migratory-nucleus-stage oocytes.

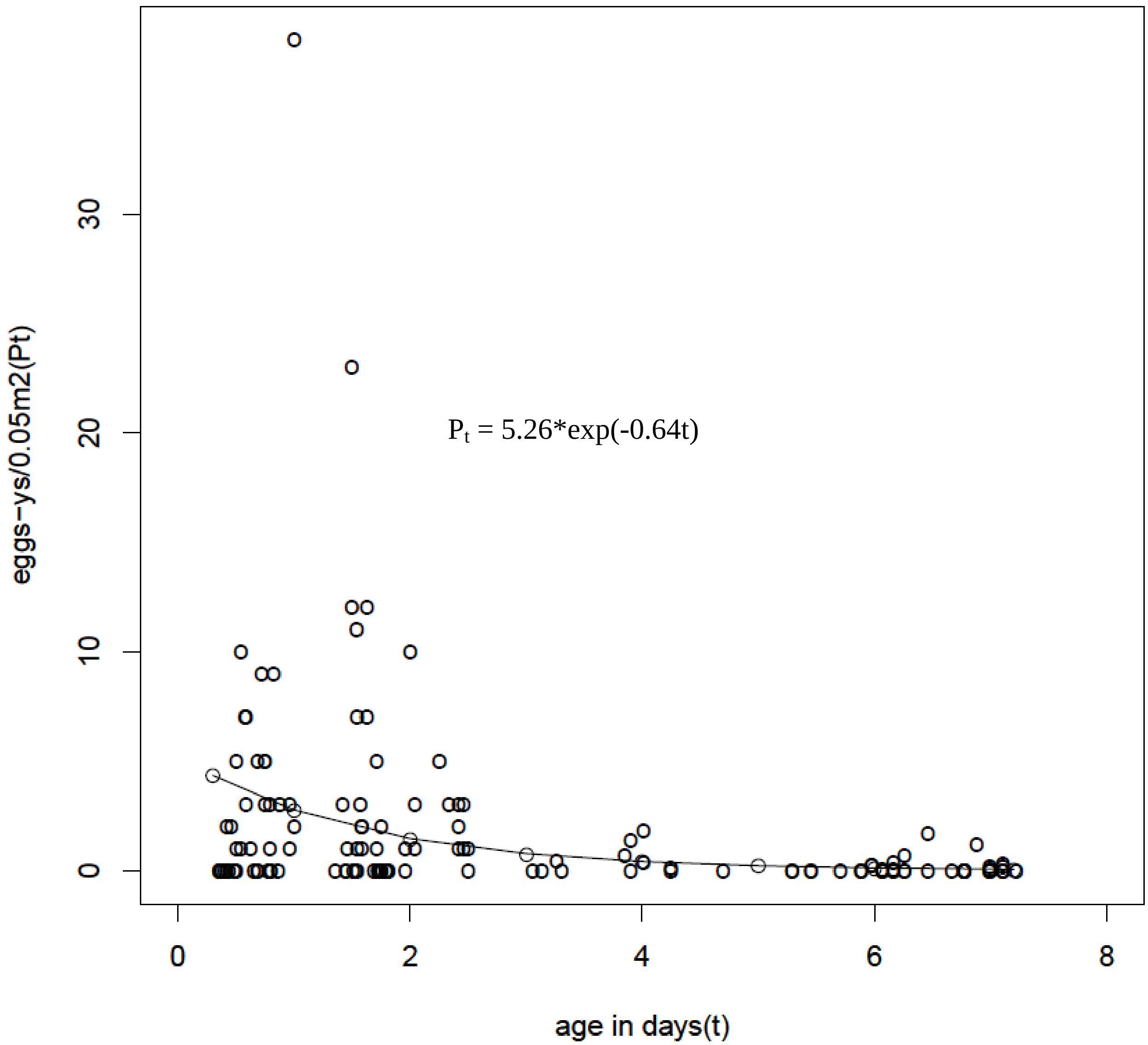

Figure 6. Embryonic mortality curve of Pacific sardines. Staged egg data were from CalVET and yolk-sac larval data were from CalVET and Bongo during April 2013, onboard *Shimada* and *Ocean Starr*. The number, 5.26, is the estimate of daily egg production at age 0 (P_0) before correction for bias.

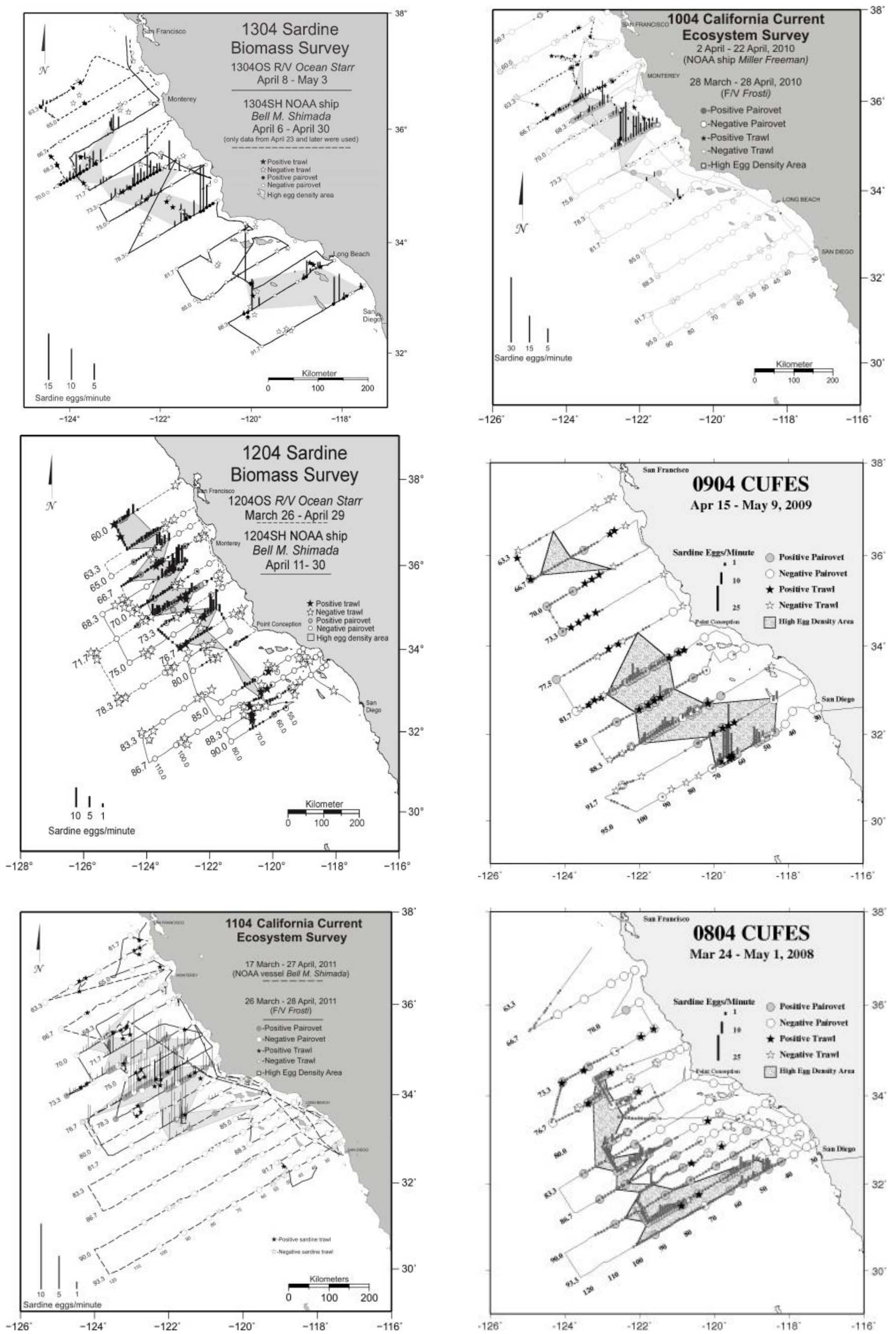

Figure 7. Trawl-egg map of Pacific sardines caught in the 2008, 2009, 2010, 2011, 2012, and 2013 DEPM survey areas. Shaded area is the high sardine egg-density area (Region 1).

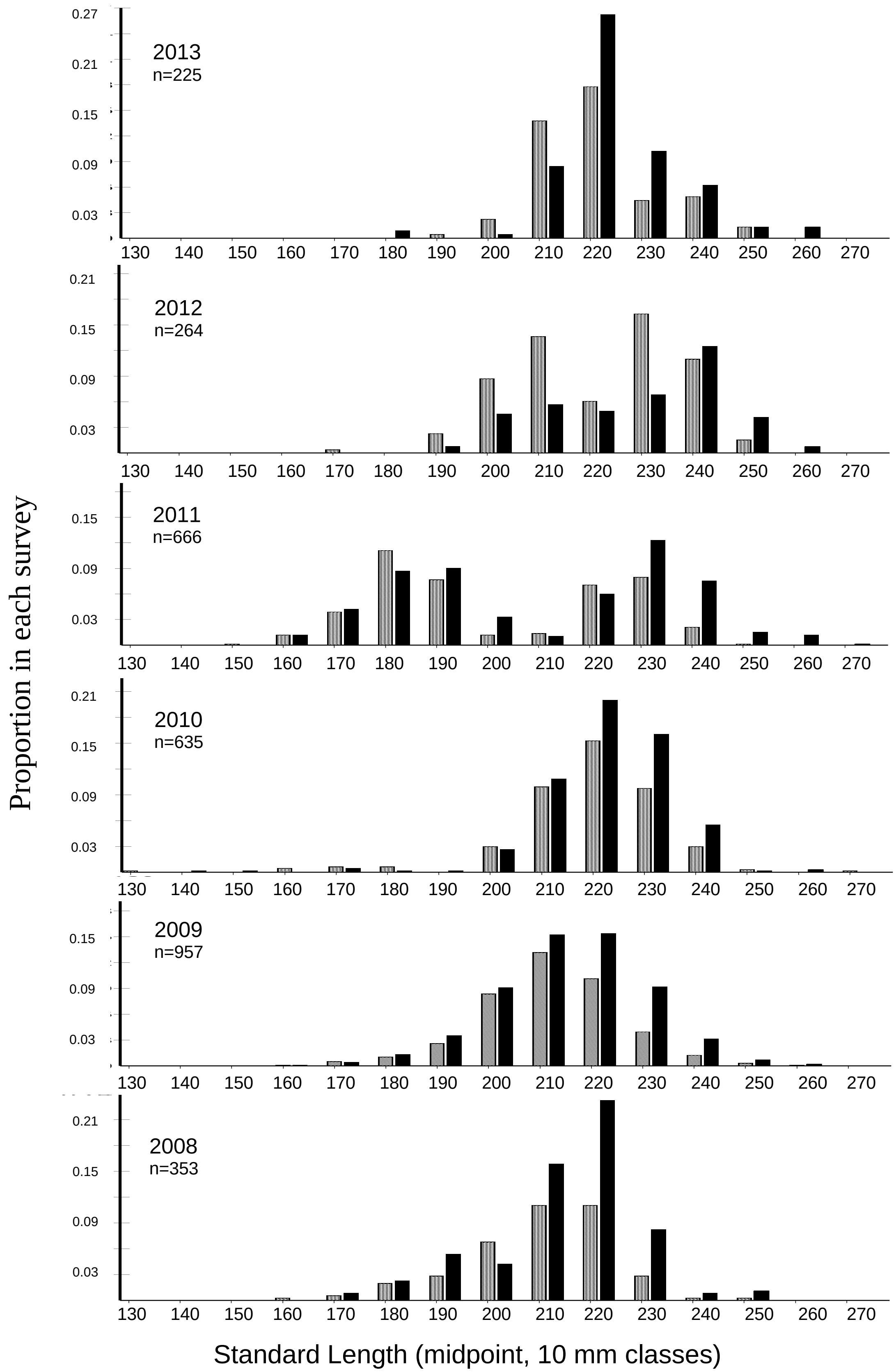

Figure 8. . Length distribution of Pacific sardines caught in the DEPM survey areas during 2008 to 2013. Males indicated by cross hatching bars and females by solid bar.

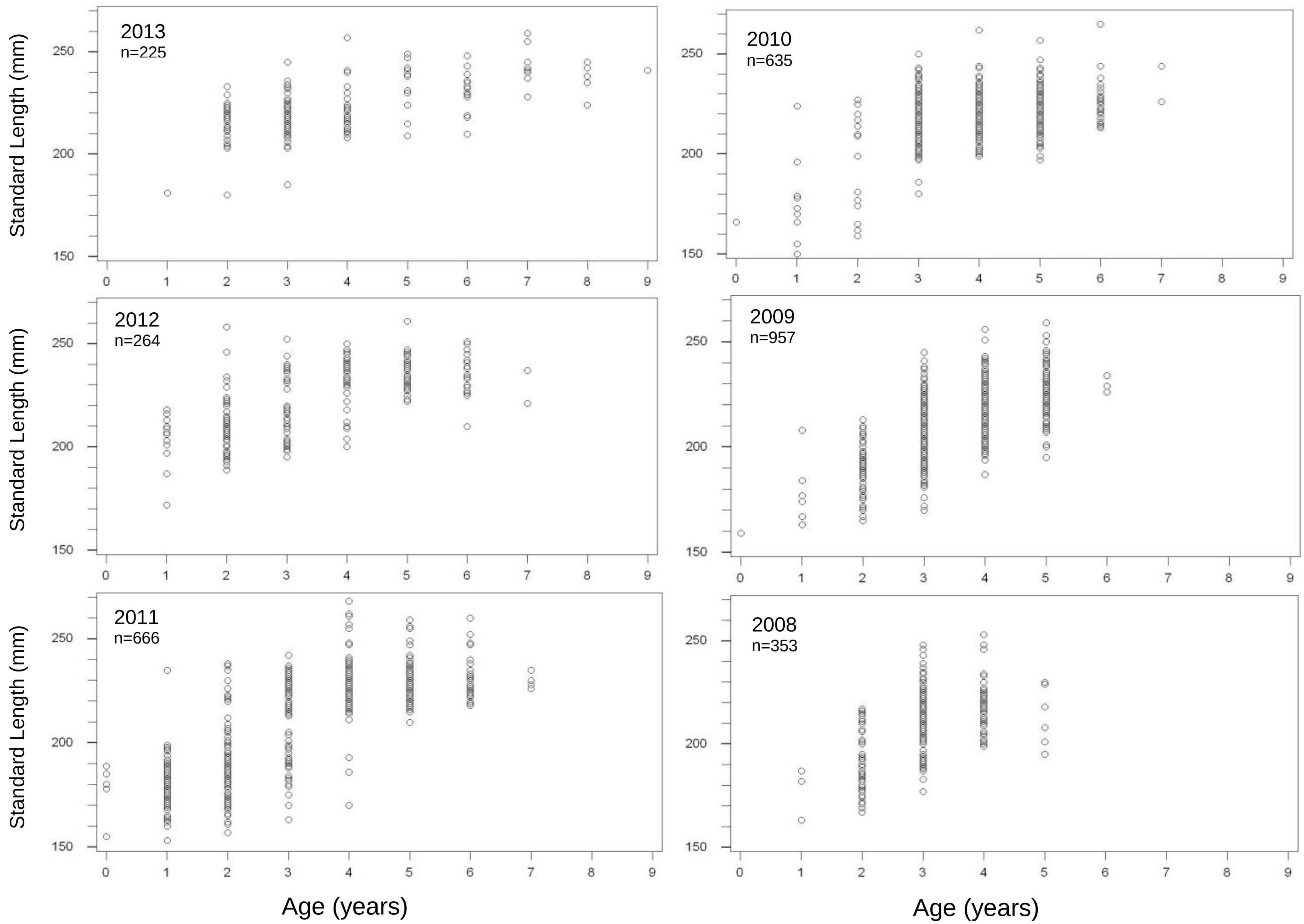

Figure 9. Distribution of age and length of Pacific sardines caught in the DEPM survey areas during 2008 to 2013.

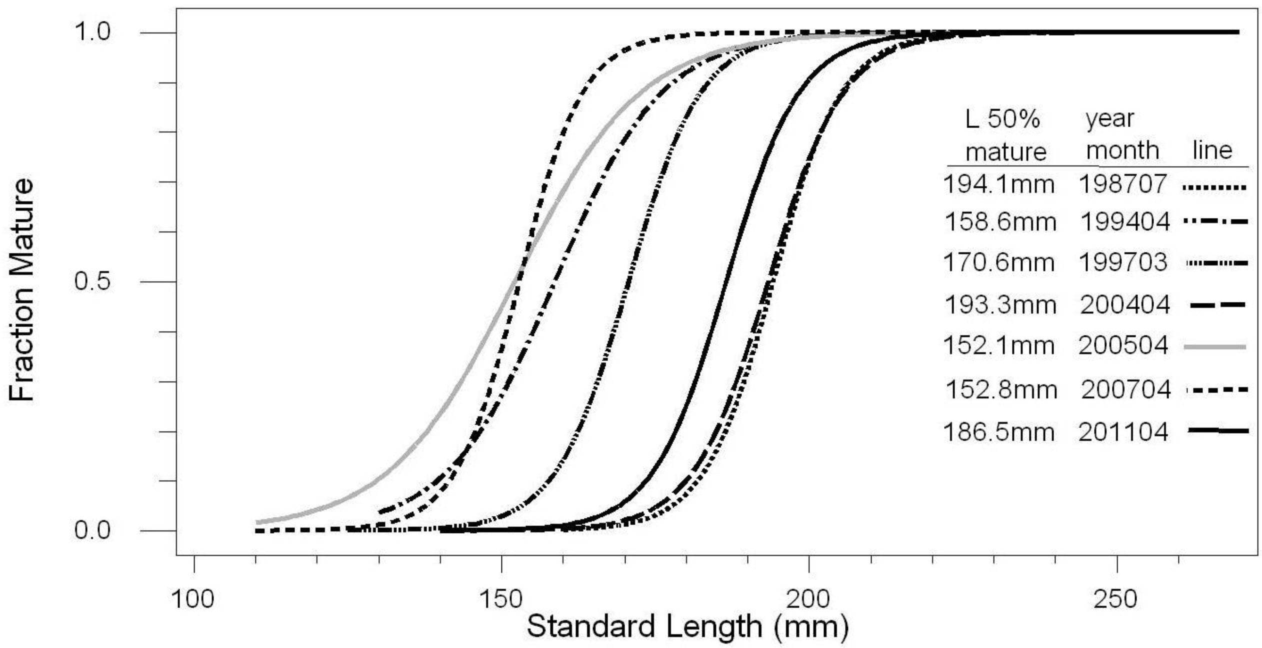

Figure 10. Fraction of Pacific sardine females randomly sampled during seven DEPM sardine surveys that were sexually mature as a function of standard length. The length at 50% maturity from the April 2011 survey was the third largest at 186.5 mm. Insufficient immature females were collected during 2002, 2008, 2009, 2010 and 2012 DEPM surveys to calculate length at 50% mature.

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